Soldering, Brazing & Welding

A Manual Of Techniques

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1 WHAT IS WELDING?

To weld is to join two pieces of metal together. Further clarification of fundamental variations is necessary of course, which then denies a simple definition.

It can just involve pressure, but this is usually aided by some form of heating and varies from the blacksmith's fire weld to electrical resistance spot welding. Heating is also used to enable bonding to occur when soldering or brazing and to melt the metal in fusion welding. Heat energy sources can be electrical, chemical, mechanical, light and sound.

A typical welding situation.

So welding can be done hot or cold, with or without pressure and with or without melting, with or without filler addition, manually or automatically and so on, but it will certainly involve the joining of metal!

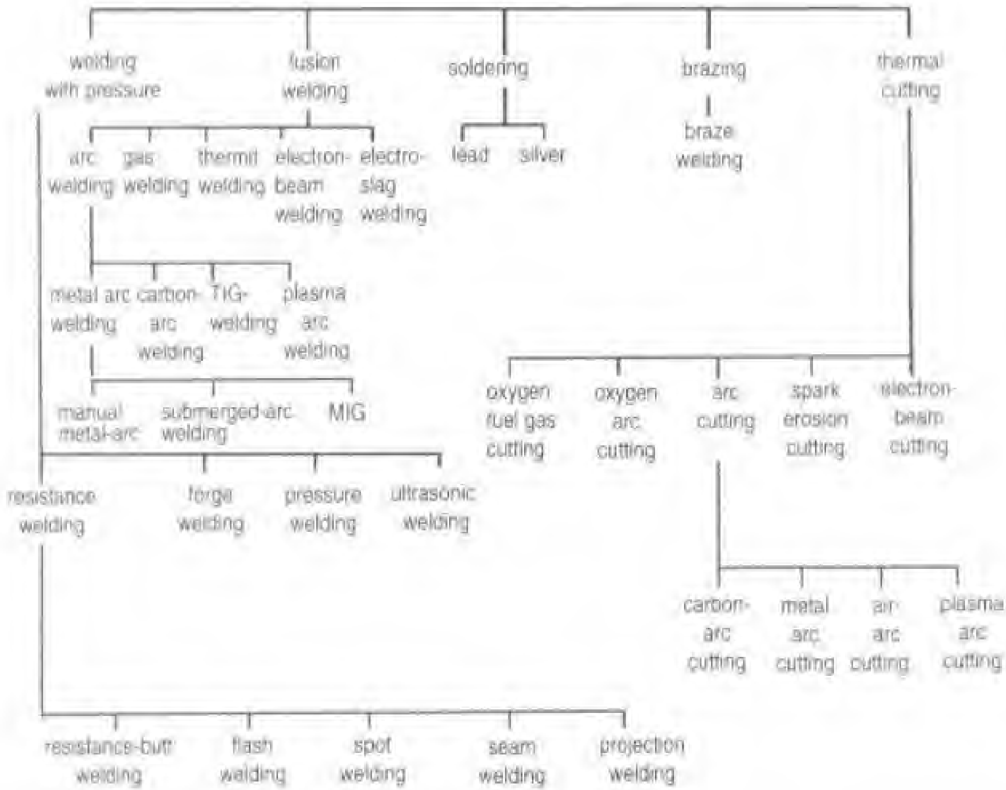
Welding is typically chosen for metal joining because it offers strength and permanency. However, in some cases these features may be undesirable and in others there may be an easier method.

Mechanical devices such as bolts, set pins, screws and so on offer some alternatives which are typically fairly easy to apply, and can be taken apart/reassembled easily, although they may perhaps lack the strength or the ability to retain fluids that welding offers.

Welding is rarely a recreational pursuit, but a means to an end (which may be recreational!), and it is relatively expensive and requires much practice to be done skilfully. It will only be adopted once all alternatives, too many to list and detail here, have been given adequate consideration.

WHICH WELDING PROCESS?

This book assumes of course that welding has been chosen as the most appropriate



Some of the more common welding processes.

joining method but now a particular welding process needs to be selected. Again advantages and disadvantages are weighed against each other to establish the process with the optimum features for the task.

A British Standard lists over ninety different welding techniques/processes many of which are automatic or used in limited special situations.

This book deals with the common techniques in widespread use which require manual skill.

Features of Processes/Techniques

1. **Lead soldering** Quite easy, especially on thin/light joints, good for dissimilar metals/thicknesses, low cost equipment. Relatively low strength.
2. **Silver soldering** Excellent with copper or brass but quite expensive.
3. **Brazing/braze welding** As soldering, but high strength and probably needs oxy-acetylene equipment. Less distortion than fusion processes.
4. **Oxy-acetylene** Gas welding; very versatile for heating, cutting, brazing and so on; high skill level – co-ordination of both hands needed.
5. **Manual metal arc (MMA)** Good for thick and dissimilar metals but tricky on thin metal and in acute corners.

6. **Metal inert gas(MIG)** Establishing optimum welding parameters needs much skill but it is easy to use, versatile and fast over a wide thickness range.

7. **Tungsten inert gas (TIG)** Needs much skill and is slow, used for high quality 'specialist' welding.

Weldable Metals

The ease with which a metal can be welded is known as its weldability and varies greatly.

All metals can be welded, with mild steel being the most common and readily weldable by all methods. Metals with high thermal conductivity require a high heat input and metals with refractory oxides need stronger fluxing. Some metals need special treatment because they are crack sensitive, and cast-iron especially may crack because it is very brittle.

The least success is experienced with very low melting point alloys, particularly when the exact composition is not known, and commonly alloys which are zinc based.

Any thickness of metal can theoretically be welded but for practical purposes fusion welding below about 0.9mm is difficult, and above 25mm (1in) warrants special consideration in relation to suitable consumables, or the need for a faster machine process.

WHERE TO WELD

The classic fabrication workshop is constructed entirely of steel and concrete, with very minor quantities of combustible materials in the form of electrode cartons etc.

For the working environment to be safe, the planning of any welding operation demands to a greater or lesser extent attention to the following.

The Workshop

1. The flammability of the fabric of the building.

A fabrication workshop producing trailers.

Fire extinguishers, an essential part of the welder's kit.

2. The storage/location of flammable items.
3. Location of fire extinguishers.
4. Adequate access for emergency services.
5. Installation of welding and other electrical equipment with particular reference to the loading on the system and ensuring that all metal is at earth potential (earthed).
6. Fume extraction at all welding sources.
7. Adequate screening between arc welding and other personnel.

The Personnel

1. Knowledge of the safety policy and its procedures including the fire drill and evacuation procedure;
2. Basic first aid knowledge;
3. Training in welding health and safety.

Basically the operator needs to know how to prevent accidents, in particular those peculiar to welding, and how to deal with them should they arise.

Finally, on an electrical note, a single phase supply is perfectly adequate, but does restrict the size of welder that can be run on the supply. For faster welding of heavier materials a three phase supply/machine is necessary.

2 NON-FUSION JOINING METHODS

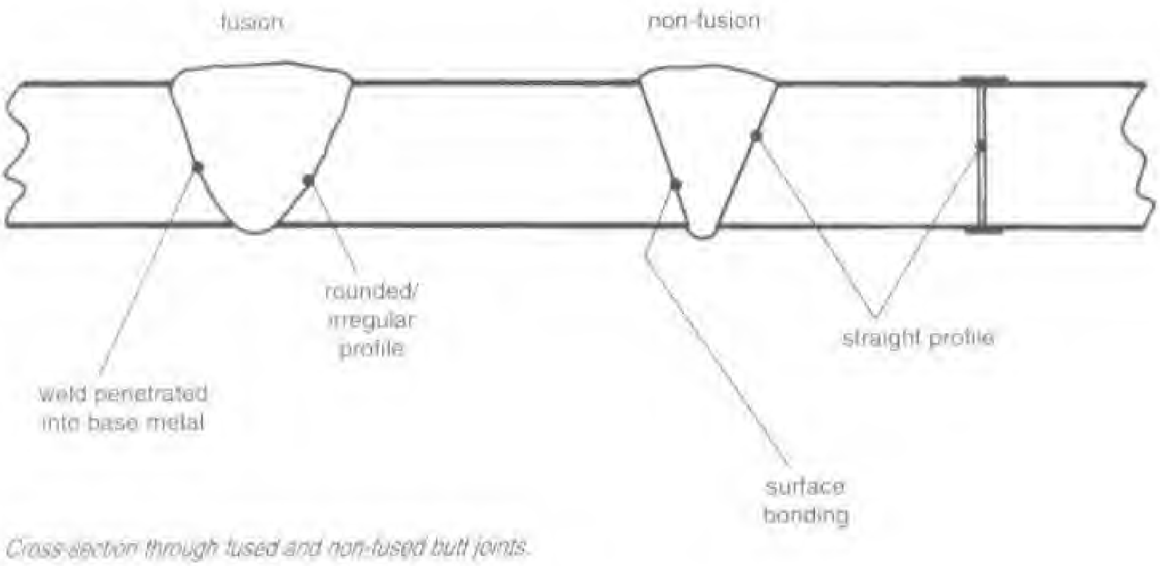
Most of this book is devoted to the making of high tensile joints where the strength is intended to match the parent metal. These are typically made by fusion welding, where the filler wire and parent metal both melt, flow together as a liquid mixture, and on solidifying form a homogeneous joint.

Since it is not always appropriate or possible to fusion weld metals together, the first sections deal with a group of non-fusion joining methods. They are:

1. Lead, or soft soldering
2. Silver, or hard soldering
3. Brazing
4. Braze, or bronze welding

In each of these methods the filler wire melts but the parent metal does not. Joint strength is achieved by 'bonding' or 'skin adhesion' and there is essentially no difference for example between solder and an adhesive, other than the need to heat solder in order to add it as a liquid. In each case a liquid is supplied to the joint which becomes solid and 'sticks' the items together.

The general trend is for an increase in melting point to be accompanied by an increase in tensile strength.



Cross-section through fused and non-fused butt joints.

LEAD SOLDERING

Historically the development of metals started with metals like tin and lead, and progressed to increasingly higher melting point materials which were more useful but more difficult to manufacture. Lead soldering has existed for hundreds of years, and rather than being superseded has become increasingly versatile and varied. It finds application in many alloy combinations, from joints as small as 150 microns on printed circuit boards to lorry radiator joints.

The following factors need to be considered when making a soldered joint:

1. Joint design/preparation
2. Heat source
3. Solder
4. Flux
5. Post cleaning.

Joint Design/Preparation

Surface Contact

Lead solder is weak in tension so soldering two thin edges butted together is unsatisfactory. All joints must be made with overlapped surfaces, where the contact area is made great enough to offset the lack of strength.

In some cases strength is gained mechanically, for example, a wire may be fed through a hole in a terminal and then soldered. This idea is developed in sheet metal joints, which are totally self-secured and where the main function of solder is to seal the joint rather than hold it together.

Fit-Up

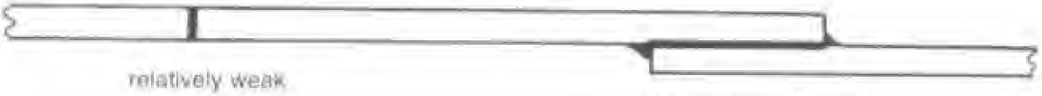
The overlapped surfaces must be in good contact. Gaps in excess of 0.25mm cause the solder to flow on each surface but not bridge across the gap. Soldering relies totally on capillary action, that is, the drawing of a liquid between two surfaces very close together, and is much too fluid to bridge gaps or build up like a weld bead. Capillary action can be ensured by using a clamp, vice, weight, press, binding wire or any device that will keep the surfaces in good contact.

Cleanliness

The best results will be obtained by having joint surfaces which are both mechanically and chemically clean, to allow the flux and solder to 'wet' evenly. Oxide and paint and so on can be removed by any abrasive means followed by degreasing with a solvent.

Heat Source

The two components of heat are (a) its intensity and (b) its volume. If bare skin is exposed to a red-hot spark or to a cup of boiling water then the spark has great inten-



Joint design for soldering

sity, and at hundreds of degrees Celsius is very hot; but the boiling water at only 100°C would inflict much more damage, because the volume of heat/amount of energy is so much greater. A change in heat is often required during welding and the decision is always one of whether more heat or hotter heat is necessary.

The heat source options for manual soldering are an iron, a flame, or a combination of both. A range of mass production sources using ovens or electric resistance etc. can be used combined with appropriate techniques.

The joint need only be heated to between 200 and 300°C, which must be supplied in the right volume to enable controlled melting of the solder.

Soldering Irons

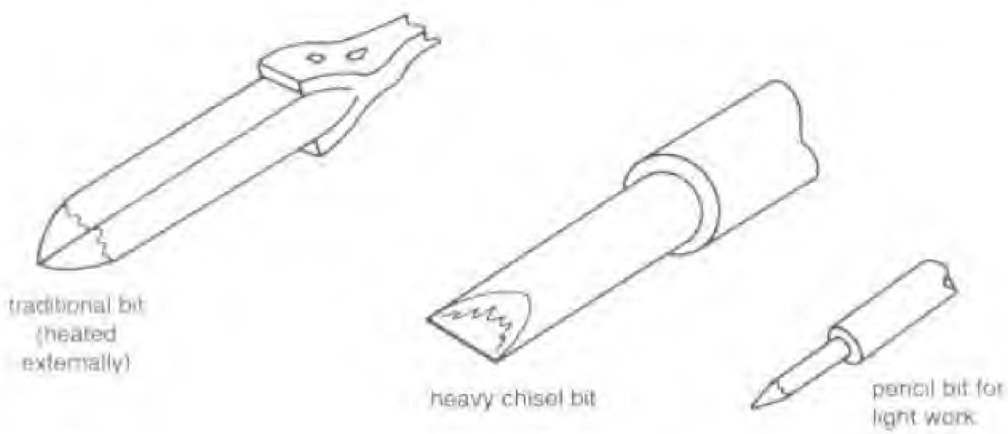
Irons traditionally had a copper bit, but the life of a modern iron is extended by being alloyed or coated with a more corrosion-resistant metal. It is heated either internally electrically or externally with a flame, and physically may vary in section/mass to hold/supply the right volume of heat.

Electric irons are rated in watts, from a 20-watt iron, which is small and suitable for light electrical connections, to a 200-watt iron, which is capable of joining thick sheet.

The shape of the bit is important. For fine electrical work it is pencil-like in section with a raked flat angle at the tip. Heavy sheet joints, on the other hand, require maximum contact so the tip end has large flat sides raked to a chisel edge.

Flame heating is best done in a purpose-made mains gas heater which provides a stable and gentle heat source. An oxy-acetylene (O/A) flame can be used but care is needed to prevent overheating, while a DIY or plumber's blowtorch will heat steadily, if somewhat slowly.

The bit is at the correct temperature when it will melt and hold a small quantity of solder. If too cold it will fail to melt solder, and when overheated solder melts instantly and runs off the bit. Not all irons are designed for continuous use. If overheated or heated for too long the bit oxidizes, becomes unusable and must be cooled and cleaned.



Types of soldering iron bit

Flame Heating

This is best done with a blowtorch, which will heat the work steadily and controllably, assuming the joint has enough mass to demand a flame or enable it to be used without damage to other parts of the component.

If the heating rate is slow then the heat supplied must be contained as much as possible. Placing the work on a firebrick surface rather than steel, working into a 'corner' built up of bricks or, at the extreme, building a brick furnace around the work will help conserve heat.

If it is necessary to resort to oxy-acetylene then the end of the flame furthest from the tip is used with a small nozzle.

This assumes that the work is relatively light but the intensity of O/A can be put to good use on heavy work, as required perhaps by the steam model engineer working in copper.

Joints which are difficult to heat with an iron may still be soldered with one if a flame is used to pre-heat and perhaps maintain a high ambient temperature, so that the heating required of the iron is reduced.

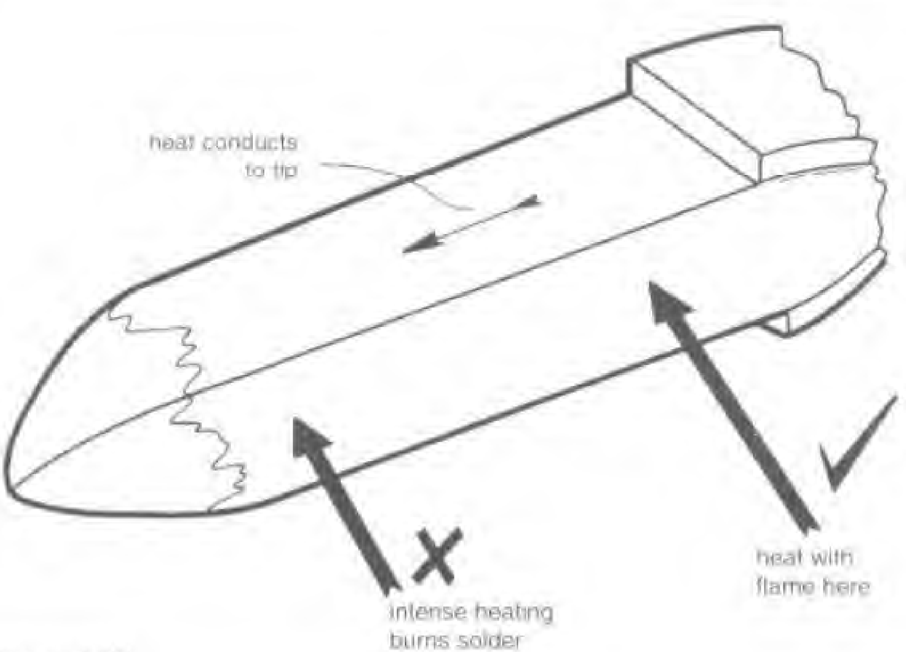
Oven Heating

Soldering can be largely automatic if the joint is preloaded with both solder and flux and placed in a furnace. The temperature of the component can be controlled very closely but it will of course be full heating rather than local.

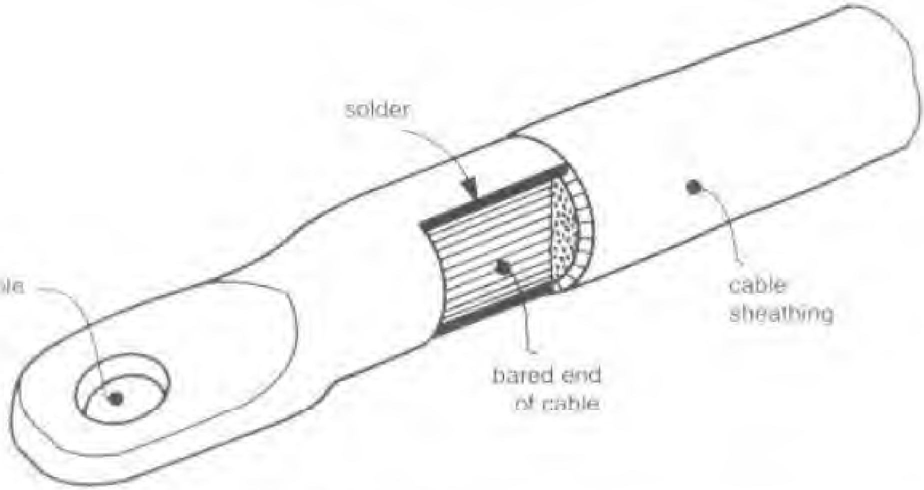
Other heating methods include electric resistance, ultrasonic, induction, hot gas and focus infra-red soldering.

Types of Solder

To appreciate the differences between solders some knowledge of metals and alloys is



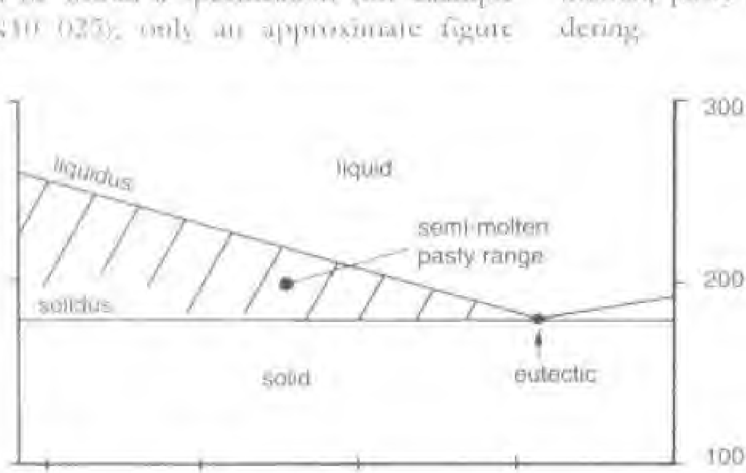
Flame heating a solid bit.



Cross-section through a flame soldered lug connector

necessary. A metal is composed of a single metallic element and has a specific melting point; for example, iron melts at 1,531°C. An alloy is a mixture of two or more metals or elements which behave in a metallic way when mixed together.

Mild steel is an alloy of iron and carbon, with some very minor additions and trace elements and melts at approximately 1,500°C. Although the various quantities will be within a specification (for example EN10 025), only an approximate figure can be quoted because the exact proportions of elements vary from one cast to another, and because the particular cast will melt over a range of temperature. It will be completely solid up to a particular temperature, partially molten over a range of temperature and completely molten at the top of this range. The lower and upper temperatures are known as the solidus and the liquidus, but it is the semi-molten, 'pasty' range that is important in soldering.



Phase diagram for tin/lead

Common Solders

Although there are many types of solder to suit a wide range of applications, the classic ones, still finding the most use, are alloys of lead and tin, in varying proportions and with other minor additions.

Within the range of tin/lead alloys commonly used, that is, from about 30–60 per cent tin, all combinations start to melt at 183°C. At a critical composition, known as a eutectic, with a composition of 62 per cent tin (38 per cent lead), it changes directly from solid to liquid. As the lead content is increased so does the liquidus, and the range over which the solder is 'pasty' gets wider and wider. This is useful to the plumber who may wish to wipe joints or adjust them slightly as they are cooling, but would be annoying to an electrician, who requires the joint to solidify immediately upon removal of the heat source.

The choice of solder varies with application and to some extent with the trade of the operator. Lead loading, for example, is a technique used by panel beaters where 'body solder', initially in the form of a stick about 25 × 5mm in cross-section, is placed in a car panel dent. The solder's high lead content and wide plastic range enable it to be pushed and moulded into shape with a wooden spatula while the solder is plastic.

Types of Flux

Fluxes will be either 'passive' or 'active' in use, that is, chemical reactions may or may not occur as it is heated.

Passive fluxes, usually in the form of a paste, are applied to the clean joint surface. As heat is applied it melts and floats over the surface, preventing oxidation by forming a liquid blanket between the air and the metal. The most common flux of this type is a resin known as 'Fluxite'.

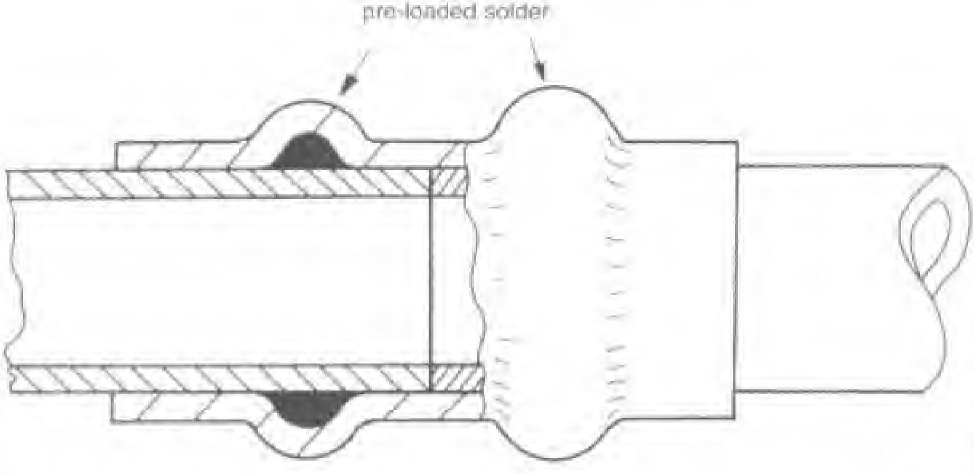
An alternative is flux-cored solder which as its name implies offers a convenient self-contained supply of passive flux.

Reactive fluxes are necessary for tasks where 'wetting' of the surface does not occur very readily; indeed it makes most soldering operations easier. 'Bakers fluid' is a popular reactive flux but it cannot be used universally because it is not always possible to remove the corrosive residual flux.

In general, passive fluxes are used wherever possible and reactive ones only where post cleaning is possible.

Tin	Melting Range	
65	183–185	Electronic instrument assemblies
60	183–188	High class tin smithing
50	183–212	General purpose copper and sheet metal
40	183–234	Best with flame rather than iron
30	183–255	Plumbing – exploiting wide plastic range

Solder types and their uses.



Cross-section through a 'yorkshire' fitting.

Solder Flux Paste

Prefluxing joints is often a good idea, but here solder particles suspended in the flux enable both to be preloaded. Heating now causes the joint to be made 'automatically'.

Post Cleaning

Removal of passive fluxes may be necessary for appearance or because the joint has to be painted. This can be done with organic solvents. Reactive fluxes must always be removed. This is done with hot soapy water and a wire brush.

Making a Soldered Joint

The joint surfaces are cleaned; a suitable flux and solder chosen, and an iron of appropriate size and shape selected. The iron is prepared and heated, the joint 'wetted' and then joined together.

Preparing the Iron

For the iron to transfer solder it must first be coated in solder itself. An overheated iron is prepared by filing down to clean metal, and then the tip is coated in flux, heated and solder applied. Excess solder can be 'wiped' off with a damp rag or sponge which will leave a thin coating, remove flux residue and enable the tip to be checked for complete coverage. If a flame is being used for heating it should be directed to the base of the bit away from the tip to prevent oxidation of the solder.

Wetting the Surfaces

The joint may sometimes be made in a single operation but usually it is much easier if it is done in two stages by coating each surface in solder first, and then joining them together.

The first stage is often inaccurately referred to as 'tinning' and more correctly known as 'wetting' the surface. The technique can be useful when brazing too and ensures that each surface is definitely coated (and easily recoverable if it is not) before commitment to making the joint.

Once solder has wetted the surface then it is simply a matter of joining solder to solder. Flux is applied to the surface at an early stage to prevent oxidation as it heats. The heated iron loaded with solder is placed on the metal and adjusted to make maximum surface contact. As the metal reaches the temperature of

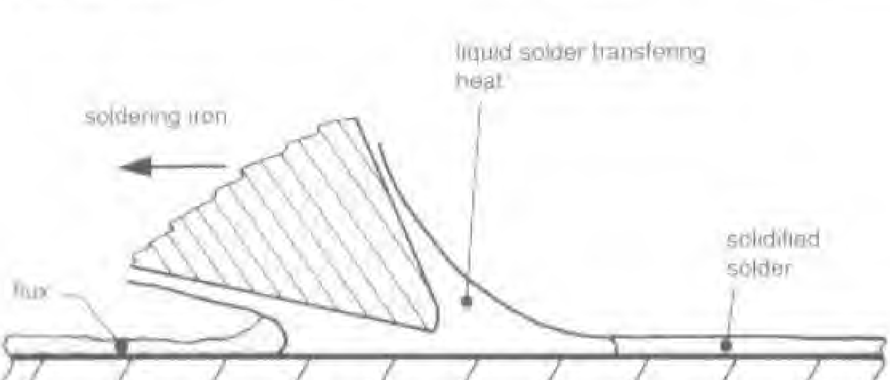
'Wetting' a sheet edge with solder.

the solder some will transfer to the surface ahead of the iron, but transfer can only be confirmed by sliding the iron along or removing it from the surface.

Excess solder may collapse and fill the joint as it is joined provided the joint is under load, but if it prevents fit-up then it can be wiped as the iron bit was.

Failure to wet may be because:

1. The surface is not clean enough.
2. Lack of flux.
3. Lack of heat – solder droplets run on the surface rather like balls of mercury.
4. Too much heat – the flux burns off and the metal oxidizes, easily done when a flame is used.
5. Lack of solder – because too little has been applied to the iron or the iron has overheated/oxidized and will not receive any. It is important to realize that transfer of heat from the iron to the metal is almost entirely via the solder, so it must be kept loaded at all times.

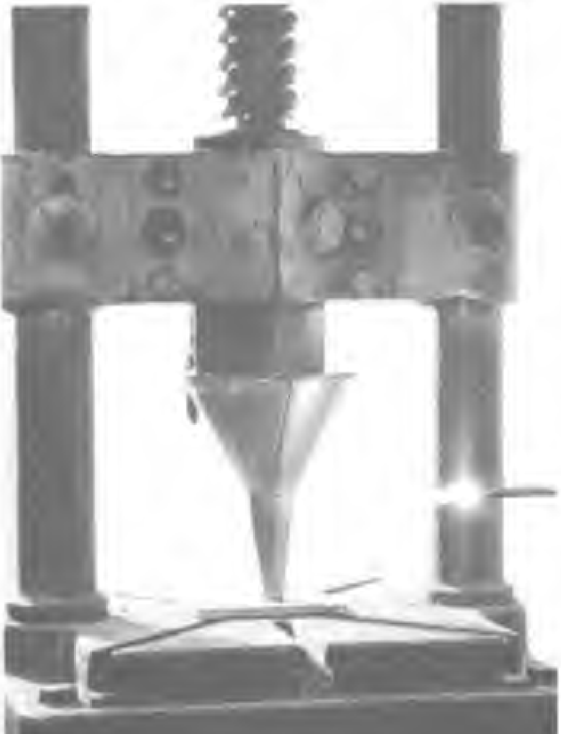


Wetting with a soldering iron

Joining Together

A small amount of passive flux is applied, then the surfaces are overlapped and heated until they run together. When heated with an iron it will need to be loaded with further solder to transfer heat and fill any gaps. The iron is directed to one edge of the joint and held in position until the heat has conducted through the joint and the full width is molten. Then the iron is moved along the joint as necessary.

Flame heating may speed this process up but heating should not be rushed otherwise the solder layer on the upper surface will oxidize before the lower one has melted. Note that some flux and a further addition of solder are still needed in this second stage.



Flame soldering a funnel under load

Cooling Rate

The best mechanical properties are obtained by fast cooling, which may also remove the aggravation of joints breaking apart because they are weak at high temperatures or have remained molten longer than expected.

Solderability of Common Metals

Copper

Readily soldered with good strength, copper's limiting factors are its high conductivity and the demand for a lot of heat, which becomes most noticeable with increase in mass/thickness. Colour matching can be a problem.

Brass

These high copper alloys are again easy to solder, with less quantity of heat required than with copper but sharing the same disadvantage of colour match.

Steel

Steel is more difficult to solder than copper or its alloys but is quite readily joined with any type of solder. Some coatings like tin, or high lead (Terne plate), are very easy, aged cadmium and zinc are difficult, and chrome impossible.

Galvanized Steel

Getting solder to wet with the zinc coating on galvanized steel is quite tricky and only possible when:

1. Concentrated hydrochloric acid is used as the flux. This must of course be handled with care and inhalation of fume be avoided as much as possible.

2. The flux must not be added till immediately prior to its need, because after only a few seconds of exposure to acid the surface corrodes and prevents wetting.

Stainless Steel

High tin content solders provide the best strength and are used in conjunction with highly reactive fluxes and if necessary hydrochloric acid. The metal must be meticulously cleaned both before soldering for the soldering to be successful and after to prevent subsequent local corrosion.

Aluminium

This metal and its alloys can be soldered using purpose-made solders and fluxes, but this is not common and tends to be restricted to production technology.

SILVER SOLDERING

In principle, lead soldering, silver soldering and brazing are identical. Each requires clean surfaces and flux to keep them clean, and relies on capillary action.

Silver soldering's excellent strength and low temperature requirement make it very useful for repairs to stainless steel, but its classic use is in the joining of brasses and copper. Note that cadmium-free types are recommended for items intended for food handling. The actual method for making a silver soldered joint is exactly as for brazing, and is described in the next section.

However, for silver soldering the flux must be designed for use up to about 650°C. The prevalent flux is known as 'easy-flo', which comes in white powder form.

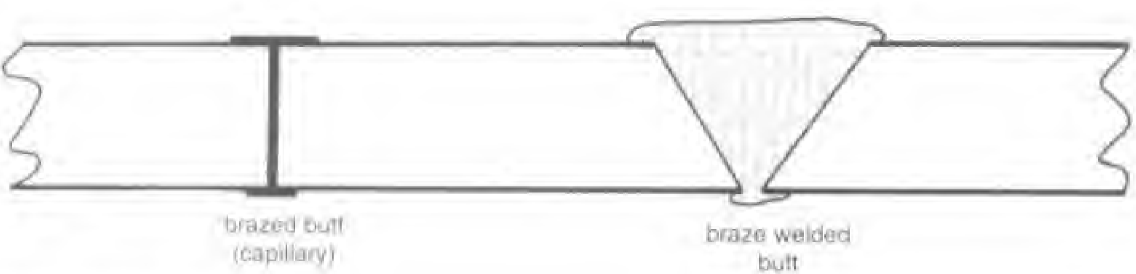
For the filler wire, the silver content can vary between 2 and 85 per cent, but is commonly in the range 22–45 per cent. Higher contents perform better but get very expensive, which is offset by the low volume requirement of capillary joints.

BRAZING AND BRAZE WELDING

Brazing and braze welding use the same filler wire, which has a strength near to that of steel but a much lower melting point.

Brazing, like all the soldering techniques, relies on capillary action, so the joint surfaces must be clean, in very close contact and heated to around 900°C in order to melt the wire.

For braze welding, a brass wire is still used but with a fusion welding technique and without melting of the parent metal. Heating



Brazed and braze welded butts.

is very local with the flame held close to the work, and by careful control of the temperature the filler bridges gaps, corners and Vs, that is, it builds up rather than thinly coating surfaces.

Braze welding is quicker than brazing and may result in less distortion because it is done at a lower temperature; however, brazing can produce an almost invisible joint when cleaned up and does not break or interrupt the joint profile.

Types of Brass Filler Wire

All fillers are primarily brass – a copper/zinc alloy – but have a further significant alloying addition, by which they are known. The most common is silicon brass, the others being manganese, nickel and aluminium.

Silicon

When metals are cast directly into their finished shape silicon addition improves fluidity, and refines the crystalline structure, making the grains small and hence stronger. Silicon strengthens brass and aids capillary action, so it is a good general purpose wire.

Manganese

This is designed particularly for the joining of cast iron and has good strength/bonding characteristics with this metal.

Nickel

Nickel imparts high strength but is the most expensive alloy addition. Typical applications are attaching tool steel tips to machine cutting tools and joining stainless steel.

Aluminium

Aluminium filler is only used for the joining or repair of aluminium bronzes.

Types of brass	Melting point	Strength tons/sq. in
silicon	875	29
manganese	895	30
nickel	910	34

Types of brazing wire.

Aluminium Alloys

The term 'brazing' implies the use of brass wire, but in fact simply describes capillary joints made above 500°C, with lower temperature ones being made by soldering. Aluminium can be brazed with an aluminium wire, typically with silicon or silicon/copper additions, which melt a little below the melting point of pure aluminium.

Types of Flux

A general purpose borax-based flux obtained in powder form is used with brass filler wires. The exception is aluminium bronze, which requires a unique flux. Proprietary fluxes are available for a range of applications and are not interchangeable – an aluminium brazing flux is not suitable for fusion welding aluminium or vice versa.

Wires with solid flux coatings or with flux embedded in a serrated surface may be preferred because they enable the joint to be made without interruption.

Heat Source

A blowtorch may provide enough heat to braze smaller items but an oxy-acetylene flame is faster and can be used to braze weld. Brazing requires a neutral heat source but for

braze welding a slightly oxidizing one is necessary to prevent zinc loss. When joining brass or working on a brass surface on a multi-run joint, the process becomes one of fusion welding and requires an increasingly oxidizing flame. Lack of oxygen in the flame is indicated by a honeycombed, porous weld.

Brazing Technique

The joint is prefluxed by mixing a little flux with water or ideally alcohol and painting it on the joint surfaces.

If possible the entire joint is heated uniformly, rather than locally as in welding, until the flux melts and turns liquid. Following a little further heating, filler is brought into contact with the joint, and if the temperature is sufficient it flows along and through the entire joint.

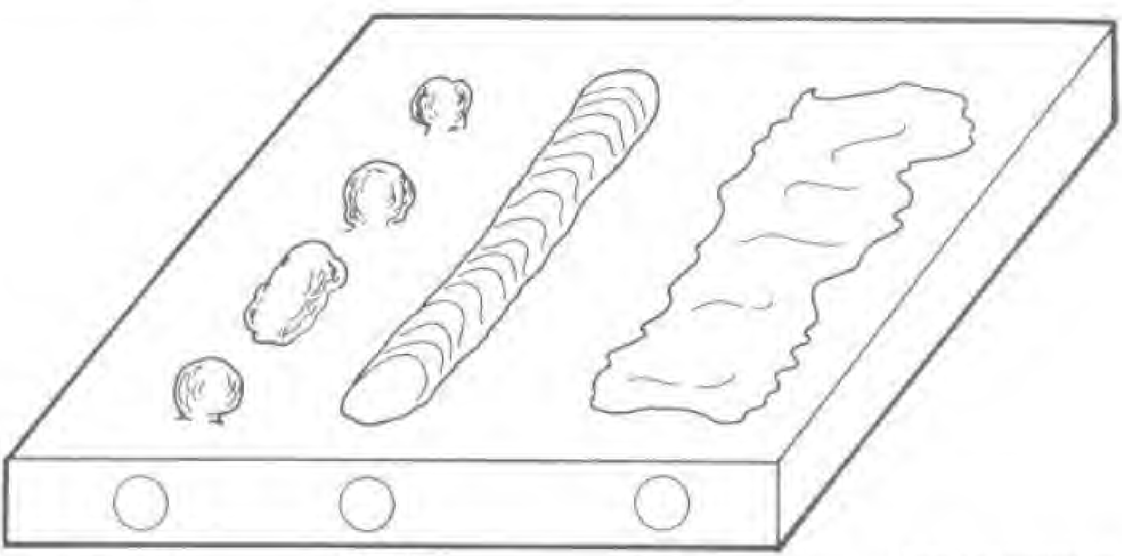
Braze Welding Technique

Prefluxing is less necessary, and is transmitted via the wire. The end of the bare wire is heated and dipped in the flux; a tuft will stick to the end. When the wire is dabbed on the heated surface initially flux transfers, and when hot enough the wire end melts and transfers too. If the joint is too cold wetting will not occur. If it is too hot then zinc oxide in the form of white fume burns off the weld. Not only is the weld depleted of zinc and the strength this imparts, but the zinc oxide fume are also very harmful when inhaled, producing zinc ague which has flu-like symptoms of shivering and aching.

To apply brass wires successfully:

1. The metal must be clean.
2. The surfaces must coat with flux before they oxidize.
3. Appropriate wire must be used.
4. The joint must be hot enough to melt the wire.
5. Enough wire must be added.

After braze welding the residual flux forms in hard, opaque islands on the weld surface



Under and overheating of brass weld beads

and is corrosive. It can be chipped off wearing suitable eye protection.

Dissimilar Metals

Some metals are difficult to melt together or form very poor alloys when they are. Providing each metal will wet with brass then the brass acts as a bridge between the two.

Cast-Iron

The low temperature of braze welding offers distinct advantages over fusion welding methods. The ductility of cast-iron is very low and stresses set up when heating a local area, or casting of a complex shape may result in cracking at another point in the metal. When fusion welding, normal practice to reduce the risk of cracking is to preheat the casting throughout to a temperature between 200 and 650°C, depending on its complexity. This equalizes expansion-induced stresses between the weld area and the remainder of the casting, but because braze welding is done at a relatively low temperature the need to preheat is practically eliminated. The cooling rate of any welded casting should always be retarded as much as possible.

Malleable Irons

This type of cast iron owes its malleability to prolonged heat treatment at about 900°C. Fusion welding above this temperature ruins the heat-treated effect but braze welding does not.

A braze weld in cast-iron.

Mild Steel

Brass fillers offer advantages where distortion control of thin metal is important, where thin sections are joined to thicker ones, or where smoothness of profile without subsequent grinding is desirable. These attributes are utilized for example in replacing an outer car wing panel.

Coated Metals

Fusion welding burns off metal coatings, reducing the corrosion resistance and producing hazardous fume. Braze welding is less disruptive and whilst a coating like zinc may melt, it will solidify back in place on cooling.

3 OXY-ACETYLENE WELDING

This is one of the earliest welding methods developed and is often referred to simply as gas welding. Welding heat is generated by burning acetylene at the end of a copper nozzle. The temperature of acetylene burned in air is very high but can be increased to 3150°C by supplying further oxygen. Other fuel gases also produce hot flames, but the only real competitor is propane, which has some advantages when used for oxy-fuel gas cutting. Oxy-acetylene equipment is very versatile compared to that of other welding processes and finds use in the ways described below.

USES

Fusion Welding

The flame is directed at the joint edges until each melts and the two flow together. On removal of the heat the material remains united.

Brazing

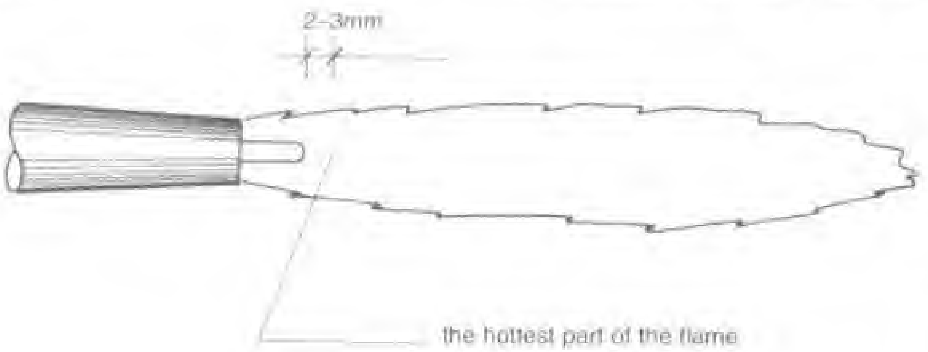
This is one of a number of joining techniques where the filler wire melts but the material being joined does not. Other heat sources might be used but oxy-acetylene is the most effective because of its high flame temperature.

Braze Welding

Carbon arc equipment can be used but does not offer the same close control of heat. The technique is very similar to fusion welding but again the joint strength relies on adhesion rather than fusion.

Silver (Hard) Soldering

A plumber's blowtorch is often adequate but the oxy-acetylene torch is superior for close control on small tasks or for providing



The oxy-acetylene flame

enough heat on very large ones.

Lead (Soft) Soldering

The oxy-acetylene flame is too intense a heat source in all but the most expert of hands but it can still be very useful. Items with a lot of mass or ones designed to lose heat such as car radiators can be readily preheated to speed up the soldering operation and sometimes are most easily completed with the flame.

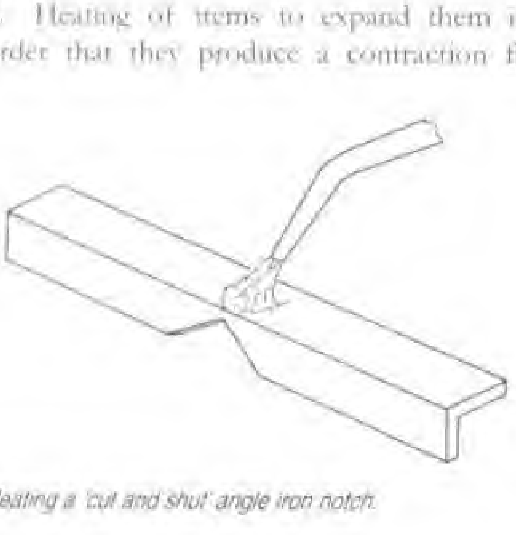
Thermal Cutting

By exchanging the welding head for a cutting attachment steels can readily be cut with ease and speed through great thicknesses.

General Heating

Whilst the oxy-acetylene torch is designed primarily for welding and cutting it provides an extremely useful source of heat for alternative uses. Some examples are:

1. Heat treatment of items such as chisels.
2. Local heating of metal in order to cause it to bend more easily and at the desired point.
3. Heating of items to expand them in order that they produce a contraction fit on cooling or perhaps to fracture corroded bonds between components, for example on car exhaust systems.



Heating a 'cut and shut' angle iron notch.

EQUIPMENT REQUIREMENTS

Oxygen

Oxygen for industrial purposes is always contained in alloy steel cylinders, painted black. BGPA codes of practice demand that all cylinders meet certain criteria; in practical terms, for welders this means that the cylinder is labelled with the type of gas, and the pressure it is charged to when full at 15°C. This information can also be found stamped onto the cylinder near its neck, along with its tare weight, serial number and so on.

Cylinder Pressure and Contents

In the past decade average cylinder pressures have risen from 175bar to 200bar, and depending on the supplier may soon change to 230bar. This has implications in the use of regulators since older ones are unlikely to be able to cope with these high pressures. At 200bar a standard large cylinder contains 9,660 litres of oxygen.

Oxygen has no smell, taste or colour that would make it easy to detect. Whilst it does not burn it is potentially extremely dangerous. Oxygen has to be present in order for things to burn, but it may not be readily recognized that by increasing the oxygen content of the atmosphere, burning is much more spontaneous and vigorous. This effect is disastrous when, for example, oxygen leaks in a confined space, but of course is put to good use in the controlled situation of an oxy-acetylene flame where further oxygen can be added in order to improve combustion.

Typical oxy-acetylene welding equipment

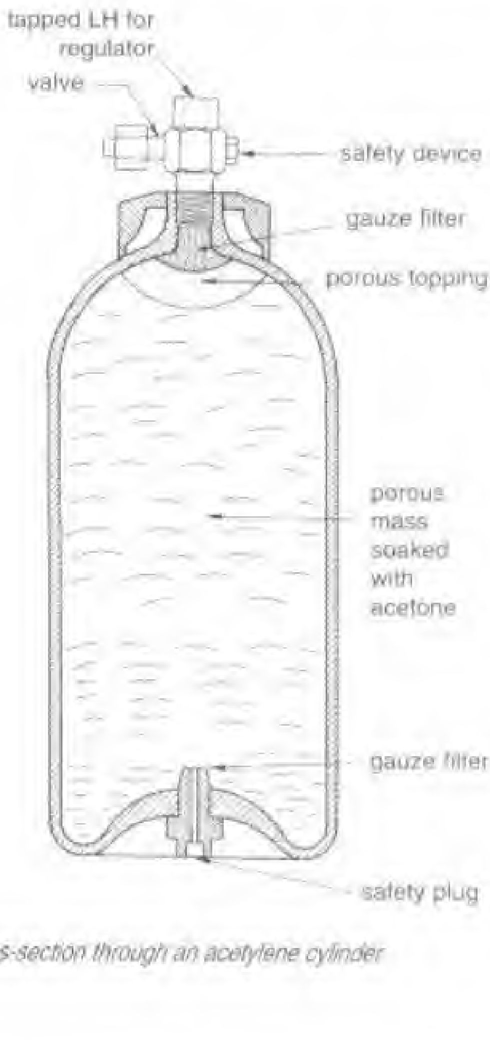
Acetylene

Like oxygen, acetylene is supplied in a variety of cylinder sizes, from very small 'portapak' ones to the large ones designed for manifold systems. Acetylene is always supplied in steel cylinders, painted maroon, which are shorter and larger in diameter than their oxygen counterparts. The cylinder will again bear a label identifying its contents, and giving pressure, weight, year of issue and so on.

Cylinder Pressure and Contents

Acetylene cannot simply be pressurized like oxygen because it becomes very unstable – if the cylinder were given a small blow with a spanner it would explode spontaneously, without requiring any form of ignition. The problem is overcome by dissolving it in acetone, a liquid which is able to dissolve twenty-five times its own volume of acetylene without occupying any further space. Hence acetylene is often referred to as 'D/A', that is, dissolved acetylene. Once in its dissolved state it can be safely pressurized to some extent.

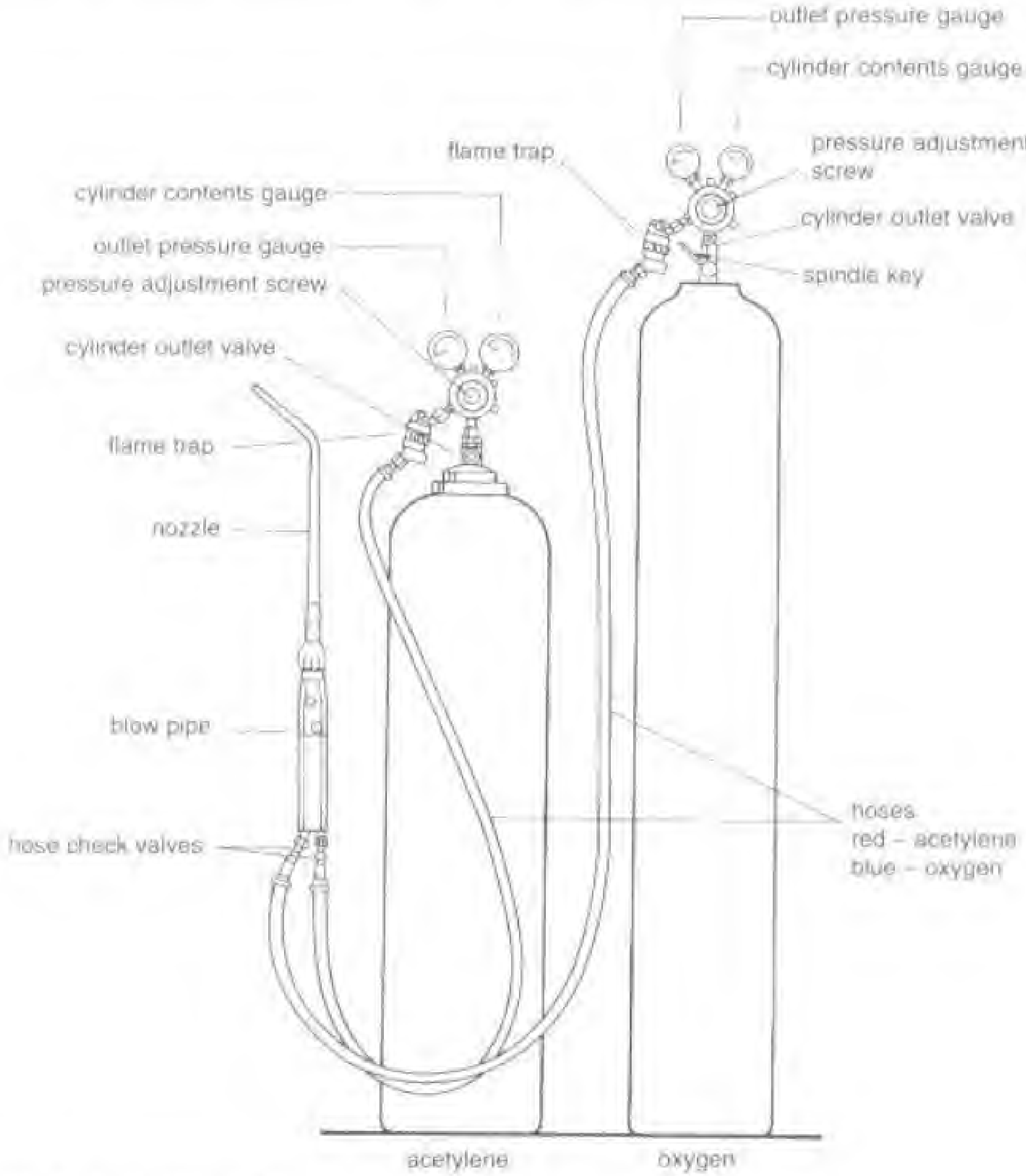
A large full acetylene cylinder will contain 6,160 litres of gas at a pressure of 15.5bar,



Cross-section through an acetylene cylinder

that is, about two-thirds of the volume of an oxygen cylinder, but at one-sixteenth of the pressure.

To prevent acetone escaping with the gas the manufacturer soaks the acetone into a solid, porous conglomerate of charcoal and cement. Thus the cylinder contains a gas, dissolved in a liquid, soaked into a solid; which accounts for the great difference in weight between oxygen and acetylene cylinders. The welding operator can prevent loss of acetone by not using the cylinder horizontally or discharging it in excess of one-fifth of remaining cylinder contents per hour.



Components of an oxy-acetylene set

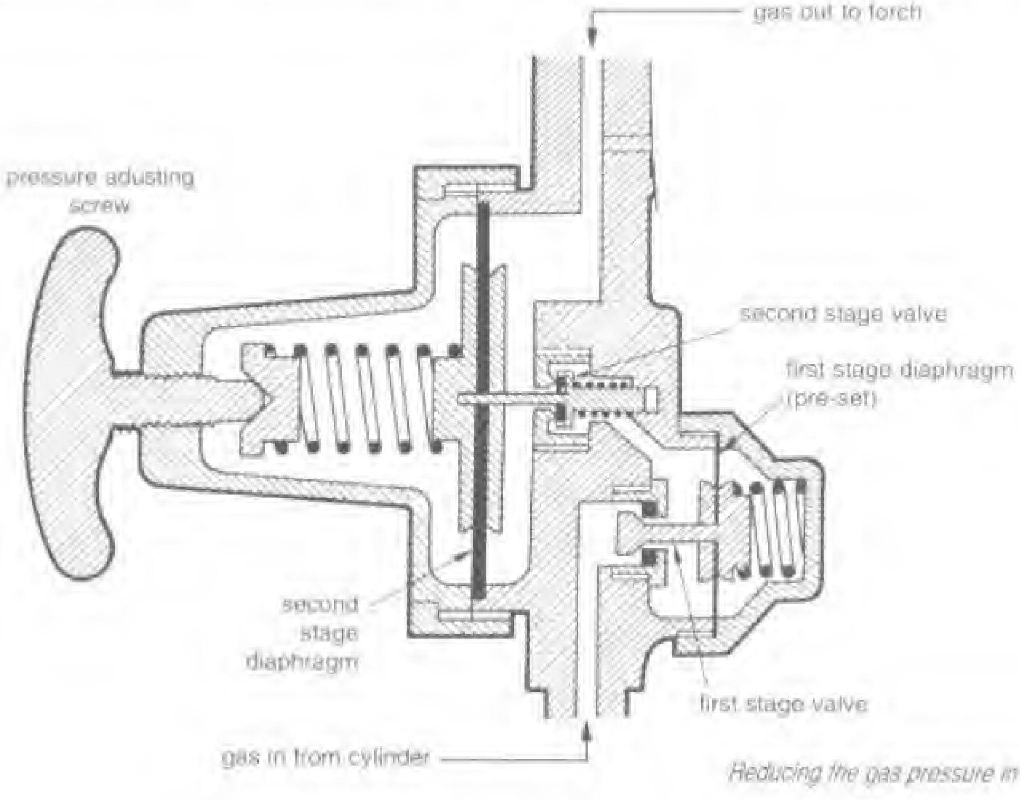
Gas Pressure Regulators

Located at the neck of the gas cylinder, these regulate the supply of gas from the cylinder to the gas delivery hose. This involves a great reduction in pressure since delivery pressures are typically only 0.14bar. In MIG and TIG welding and to some extent gas cutting, some variation in delivery pressure is tolerable. In gas welding this variation would produce an unacceptable change in the welding flame, thus the pressure regulator not only has to make an huge reduction in pressure but it also has to provide a very uniform pressure/flow at the welding tip.

Regulators can be either single stage or two stage. Single-stage ones are used where some variation in output pressure will not affect welding quality; with these, pressure reduction occurs in a single stage – in the case of a full oxygen cylinder this may be from 200bar to 0.14bar. This is achieved by means of a manually adjustable spring opposing a flexible diaphragm (see diagram below), so that as the pressure builds up against the diaphragm it closes the valve and cuts off the supply. Flow of gas causes the pressure to drop and the valve to re-open, allowing further gas to enter the regulator.

Single stage regulators are 'small', have a single gauge which indicates the cylinder pressure only, and an adjustment knob which is wound in along a stem which may possibly be graduated to provide a rough guide of delivery pressure.

A two-stage regulator is effectively two single-stage regulators placed in line, but contained within one housing. The first stage is pre-set by the manufacturer and is



Reducing the gas pressure in two stages

completely automatic. It reduces the pressure by about 90 per cent, which means that the output pressure from the first stage of an oxygen cylinder is about 20bar.

The second stage therefore has to work over a pressure range of 0–20 rather than 0–200bar, providing a very constant output pressure. This stage is adjustable by means of an adjustment screw/knob at the front of the regulator.

Two-stage regulators will usually have two gauges, the second being desirable in order to know precisely the delivery pressure.

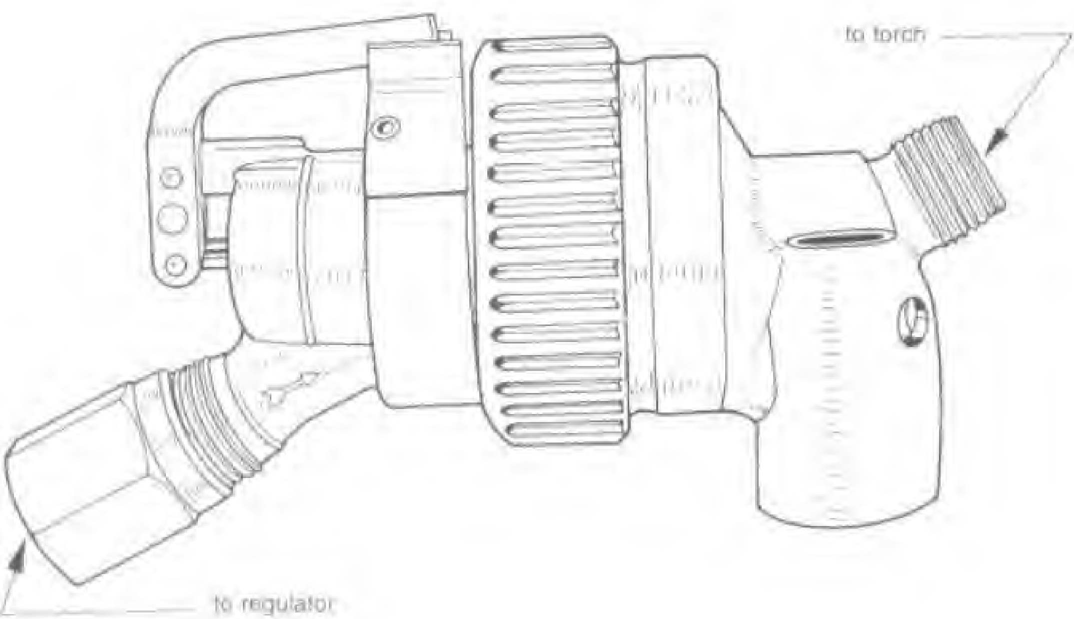
Flashback Arrestors

The flashback arrestor is located between the regulator and the gas hose. Its function is entirely a safety one: it has no primary effect on the operation of the equipment. It renders the equipment much safer to use by functioning in the following ways:

1. A sintered metal flame trap extinguishes any flames that may burn back through the gas hose. Therefore gas inside the cylinder cannot be ignited in this way.
2. A valve cuts off the supply in the event of a flashback or the pressure wave accompanying 1. above.
3. The valve also cuts off the supply in the event of pressure fluctuations occurring over a length of time.

There are three quite different types of arrestor, varying in their ease of use, and very significantly in price!

The best has a trip lever located on the outside of the body, which provides a visual guide that the arrestor has been activated. This needs to be pushed back into place before the system will operate normally again.



A flashback arrestor

Before resetting, consideration must be given to why the arrestor activated. The common causes are incorrect lighting up procedures, pressure settings, or use of torch.

A second type, less expensive and of more simple construction, is one which activates like the one above but is more complicated to reset: it has to be removed from the line, and a pin, attached to the arrestor with a chain, must be inserted in the body to reset the valve.

The third type is a disposable one – once activated it has to be replaced. This may be economical for the experienced but is definitely not recommended for the beginner!

If the arrestor is inadvertently fitted the wrong way around then no gas will flow through the hose to the torch. This provides a useful test for its effectiveness: it should not leak at a delivery pressure of 0.6bar.

Gas Hoses

Gas hoses provide a means of flexible delivery of gas from the regulator to the welding torch and vary in the following ways.

Like the other parts of the system, hoses are colour coded,with red for acetylene and blue for oxygen. For ease of manufacture they are typically of the same quality, quite often bonded together as a pair, with the oxygen hose painted blue. It is safer to split these before use.

Size

The wall thickness and diameter of the hoses vary and relate to the maximum delivery pressure. The high pressures demanded for gas cutting thick steel may warrant heavy hoses but if the anticipated use is for welding and cutting thicknesses up to 20mm then light hoses will be easier to manipulate in use.

Length

The standard length is 5m, but this can be doubled or may get shorter following repair. In either case a proprietary hose coupler should be used attached with 'o' clips. Any cheaper or handier alternatives are fraught with danger. Hoses are easier to use when short and should be completely unwound before use. It is therefore pointless to buy or make up unnecessarily long hoses.

Fittings

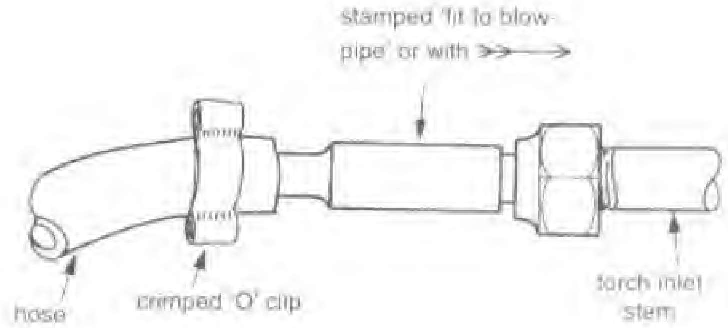
One end of a new hose will have a 'hose check valve' fitted by the manufacturer. It is a longer metal fitting than that at the other end and will have stamped on it 'fit to blowpipe'. The unit contains a disc, which is free to move up and down a short chamber. Pushed one way it allows gas to flow on through, but any back pressure, perhaps following an explosion at the welding tip, sends the disc back and cuts off the gas supply. This provides a high degree of safety and support but does not remove the need for a flashback arrestor.

Torch

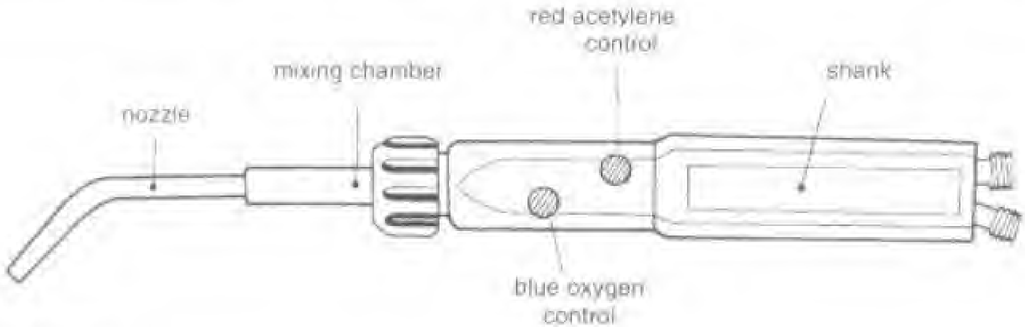
The torch, or blowpipe, consists of three main parts: the shank, that is, the body of the torch, the mixing chamber, and the nozzle.

Shank

The shank is typically an aluminium casting, although recently stainless steel ones have emerged, which are even more durable but also more expensive. It houses the control valves for each gas which again are colour coded.



Identifying a hose-check valve.



The O/A torch

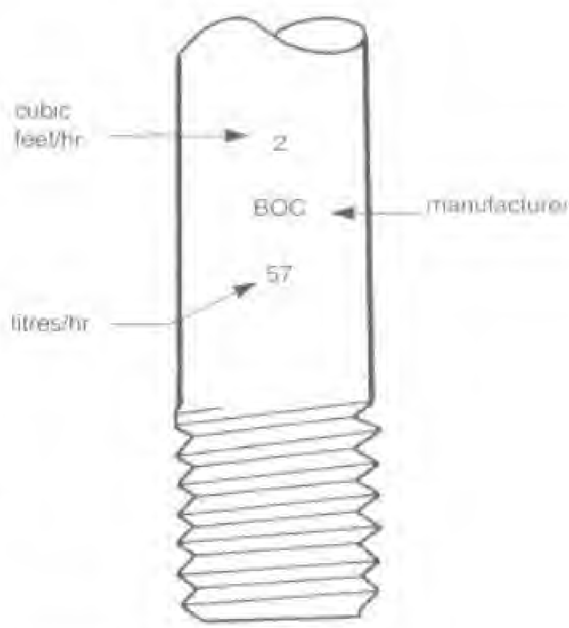
Mixing Chamber

The controlled gas supply flows on through the shank and into this unit, where the gases actually mix together. This small, complex item is made of brass, perhaps chrome plated, and is screwed onto the end of the shank.

Nozzle

This is made of copper and is screwed into the end of the mixing chamber. Since copper is a fairly soft metal it can be damaged quite easily. The threaded end will not screw in or seal properly if the end is damaged and the flame at the other end will be distorted and lack 'focus' if it suffers damage.

Nozzles are identified with a number, which indicates their consumption of each gas in cubic feet per hour. If the



Identifying a No. 2 nozzle.

recommended setting up/lighting up procedure is followed then a No. 7 nozzle will use about 7cu. ft/hr of each gas; changing the nozzle size changes the volume of gas and in turn the volume of energy supplied to the weld area, which will influence the rate at which the metal heats up. If the flame is correctly set then the temperature will be the same for all nozzles, that is, 3,150°C.

To withstand the increase in heat radiated from the weld area nozzles with a larger capacity are made physically larger too.

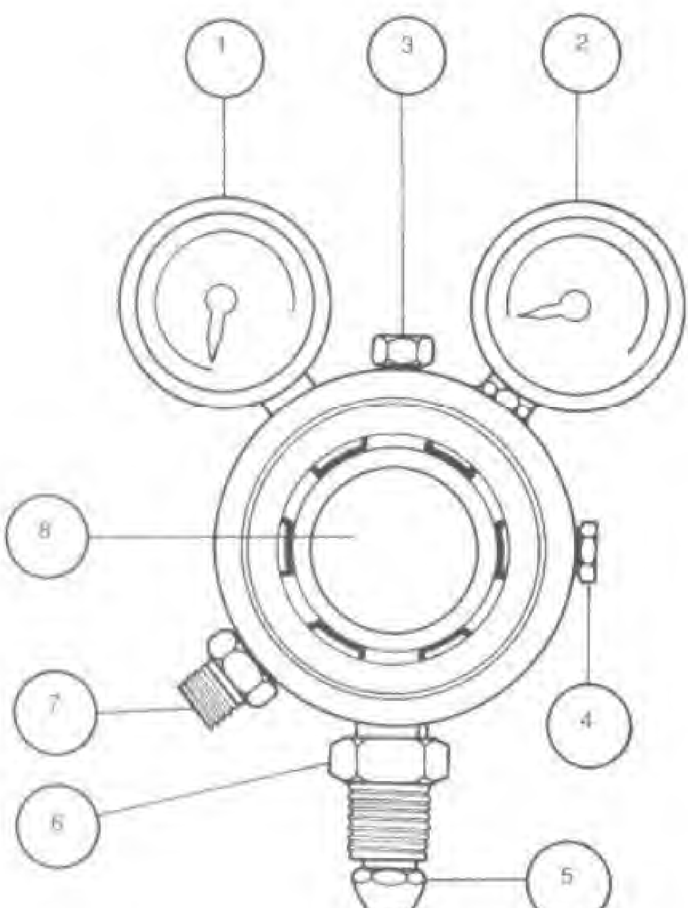
OBTAINING EQUIPMENT

Gas Supply

Gas can be obtained from a welding gas supplier. Most should offer competitive prices, and provide good service and technical information on all aspects of welding, including the handling, transportation and use of industrial gases.

Regulators

For reliability and safety, the best regulator



1 Outlet pressure gauge
2 Cylinder pressure gauge
3 Pressure relief valve
4 Plug
5 Regulator inlet
6 Inlet nut
7 Regulator outlet
8 Label giving gas inlet and outlet pressures

A two-stage regulator.

will be one made to BS 5741/BS 7650 (in the UK) or equivalent, which should be evident on the body of the regulator. It must be capable of handling the pressure of a full cylinder; for oxygen this would be 200bar.

Flashback Arrestors/Hoses

There are three types of arrestor as discussed above but beyond this there is very little variation. Similarly once the size/length of a hose has been selected then variation in price will be related to the competitiveness of the supplier.

Torches

Many designs of torch are available, with variations in weight and small differences in appearance, but all essentially working in the same way.

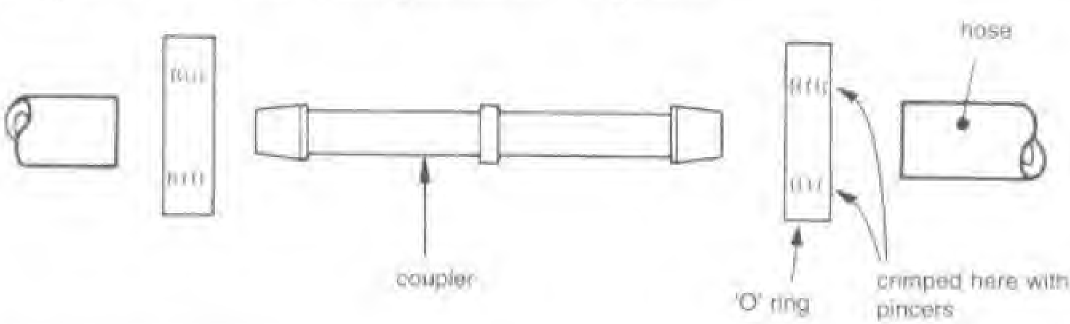
MAINTAINING AND REPLACING EQUIPMENT

Cylinders must be turned off when not in use and when the cylinder is empty prior to removing the regulator. They should be returned for refill before they are completely exhausted, ideally when the pressure has dropped to about 1bar. These precautions will prevent air backfilling into the cylinder.

No maintenance is necessary or permitted on cylinders. If a cylinder is thought to be unsafe in any way, for example if the gland nut at the neck leaks, then return it to the supplier and accept a replacement.

Regulators, flashback arrestors and torches may each cease to perform correctly after prolonged use or time. These items require expert attention and no attempt should be made to repair them. It is customary to have faulty equipment service-exchanged, that is replaced with a fully guaranteed, restored item at a lower cost than purchasing a new replacement.

Hoses require a somewhat subjective assessment regarding their safety. If the first layer of canvas shows, as a result of abrasion or burning, or if the hose is heard to 'crack' when squeezed tightly through 180 degrees in the hand, or of course if it leaks, then repair or replacement is necessary. Hoses must be repaired properly, by cutting out the suspect length, then reconnecting with a proprietary hose connector, held in place with 'o' clips. Anything less than this is likely to be dangerous. If copper is used in repairing the acetylene line, for example, a chemical compound is formed which in time becomes explosive.



A hose connector and fittings

Similarly the chemical reaction between oxygen under pressure and oil or grease or similar compounds must be avoided, and particular mention of this is made on the cylinder label. The reaction here is a spontaneous explosion. When making gas connections no lubricants, jointing compounds or sealers should be used because they are susceptible to the same reactions.

ASSEMBLING THE EQUIPMENT

Throughout assembly of the components it will quickly become evident that the system is colour coded – acetylene fittings are all red and oxygen fittings are always blue. The exceptions are the cylinders, which are maroon and black respectively.

It will also be apparent that there are two types of thread: those on similar fittings will be the same size and pitch, but threads for oxygen are conventionally right hand, and those for acetylene left hand. Left-hand threads on gas fittings of any sort indicate that the gas is combustible.

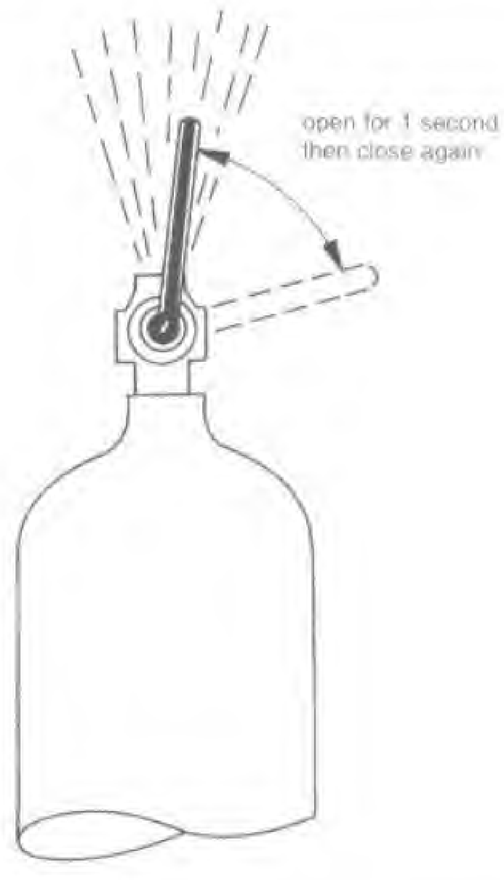
The explosive nature of the gas is further highlighted with 'notched' nuts used on all connections, a feature peculiar to acetylene.

Gas Cylinders

There are two stages in the preparation of cylinders.

First the plastic cap needs to be broken and unscrewed from the neck of each cylinder in readiness to receive its gas regulator. An empty gas cylinder can be recognized by the absence of this cap and it is customary to mark M.T. (empty!) on it with chalk.

The second stage is to 'sniff' the cylinder. This is done by opening the cylinder valve and allowing gas to escape violently for about a second before closing the valve again; this is done to remove any debris, dust, water and so on from the connecting surfaces.



'Sniffing' a cylinder.

Operation of the valve will vary depending on the supplier of the gas. It may be opened by turning a handwheel or by inserting and turning a cylinder key in the direction indicated on the valve assembly.

Note that at all times the cylinders must be stored and used in an upright position. If they must be transported horizontally then invert them and leave for about half an hour

before using, so that the acetone is allowed to settle in the acetylene cylinder.

Regulators

Although heavy and made mainly of metal, regulators must be treated as precision instruments – only then will they function reliably and give long service. New regulators will need to have the protective caps removed from the threaded gas connections. Older ones should be inspected for signs of damage on the mating surfaces, distortion to the stem, damage to the gauges or indicator needles that do not zero, before reusing. Be particularly cautious with regulators manufactured before 1989, since they may not withstand the cylinder pressure.

The regulator stem is inserted into the cylinder neck, initially hand tightened and then finished off with a gentle hammer tap on the spanner. Consider at this point whether the regulator fouls access to the cylinder key/knob and if necessary slacken and rotate the regulator to a more convenient position.

Finally, open each cylinder in turn and purge the regulator with gas. This will also drive through any dust present.

Flashback Arrestors

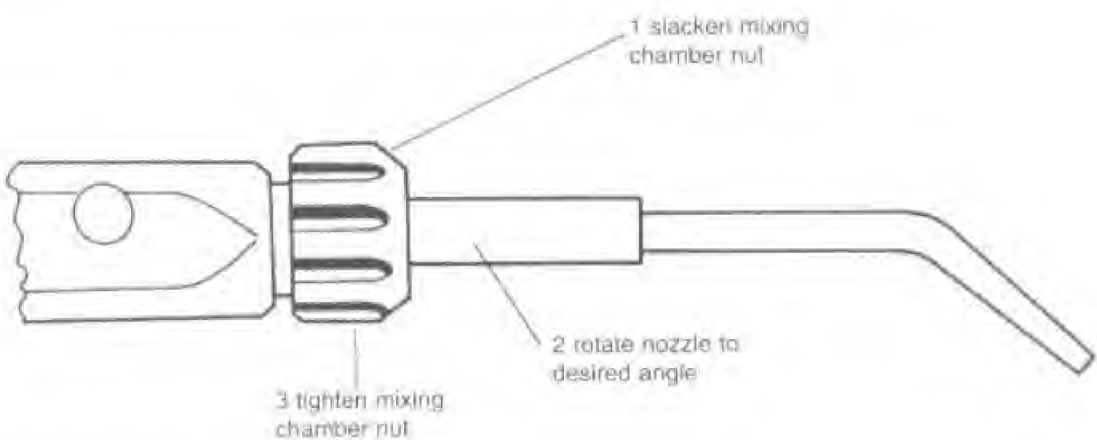
Again remove the dust caps if the arrestor is new, then fit and purge. You will now know if it was put on the right way around!

Hoses

Fit, ensuring each hose check valve is at the torch end, and purge. If the hoses are bonded together then split them before fitting so that they will be quite separate when used.

Torch

Fit and purge, then select and insert a nozzle to suit the work in hand. If at this stage the nozzle points at an angle which makes it awkward to use, slacken the mixing chamber connection, rotate the nozzle to the desired angle and retighten the mixing chamber connector.



Adjusting the nozzle angle.

Testing

On completion of assembly all joints must be tested for leaks. 'Teepol' is painted on each threaded joint with the equipment turned on and under pressure. Bubbles blowing at a joint indicate that the connection is either faulty or needs further tightening.

LOCATION OF EQUIPMENT

It is too dangerous to allow the cylinders to stand freely so a method of restraint is necessary.

Initially it may be easiest and satisfactory to hold them against a wall or to the end of the workbench with either a chain or a hinged strap. For full mobility, a cylinder trolley is preferable, and these also hold the cylinders upright. These can be purchased, or could perhaps make a useful first welding task.

GAS WELDING ACCESSORIES

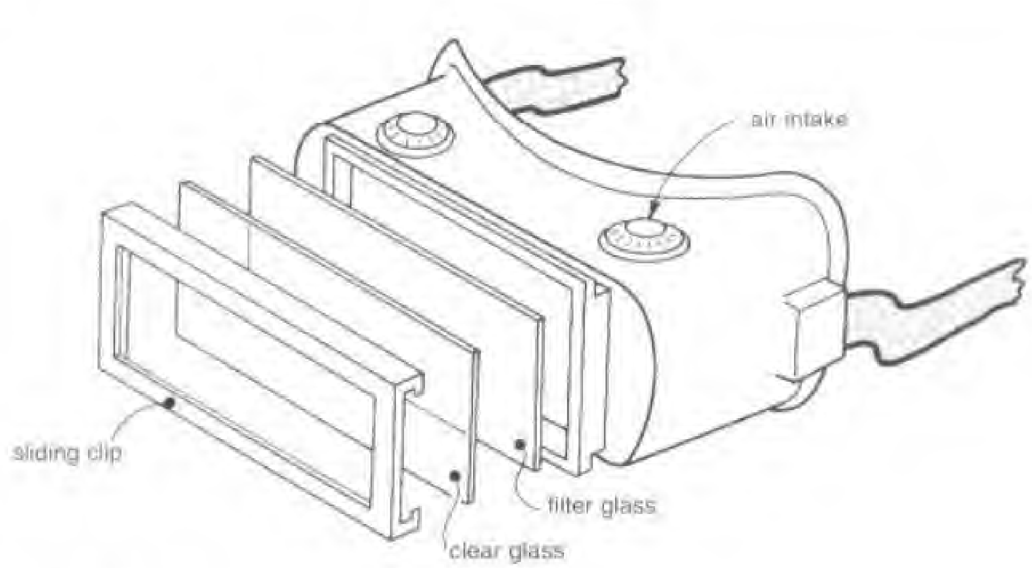
In addition to the basic equipment requirements, a number of other items may be either essential or useful.

Welding Goggles

These are absolutely essential in order to see the welding operation clearly without eyestrain and without sparks and spatter entering the eyes. The weld pool is viewed through a coloured filter glass which reduces the brightness to a comfortable level. These are made to BS 679 (or similar standard overseas) and for most work a GWF3 is used. Heavier, brighter work may demand a GWF4 or a GWF5, the other two common grades.

The coloured filter glass is protected by a plain glass or plastic cover which gets spattered up and is inexpensive to replace.

Some goggles can also be used for grinding



Gas welding goggles

because they have a hinged filter glass which lifts up to expose a clear glass, but all goggles are made to BS 1542 or equivalent.

Protective Clothing

A number of factors determine what protective clothing is needed. A minor task, done on the bench, undertaken in 'old' clothing may not warrant any further consideration. Protective clothing will, however, be a major consideration if welding overhead whilst beneath a motor-vehicle. In this case a cap would be necessary in addition to the usual overalls and gloves. Cotton clothing without any frays is best for combatting welding sparks, which despite the most vigilant efforts will still tend to find their way into socks, up sleeves and down necks. Beware!

Flame Ignition

Whilst a spark in the wrong place can have devastating results it is impossible to get started without some form of ignition. Flint guns of various design are effective and safe. Matches and cigarette lighters are equally effective but potentially lethal if kept in a pocket during welding.

Fire Extinguisher

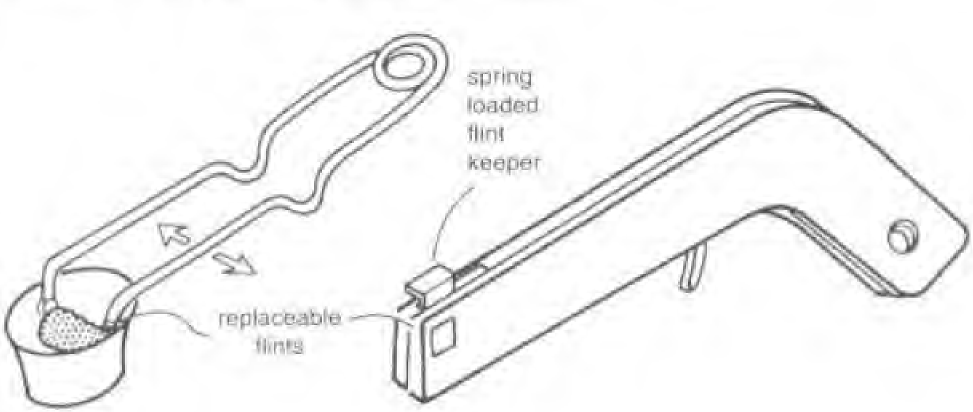
The need to have one of these always to hand during any welding activity must be self evident. Consideration should, however, be given to the type.

Water is excellent and reduces the likelihood of further ignition but is not a wise choice when working near to electrical equipment!

Other possibilities are CO_2, Foam, and BCF, each having its own merits and disadvantages.

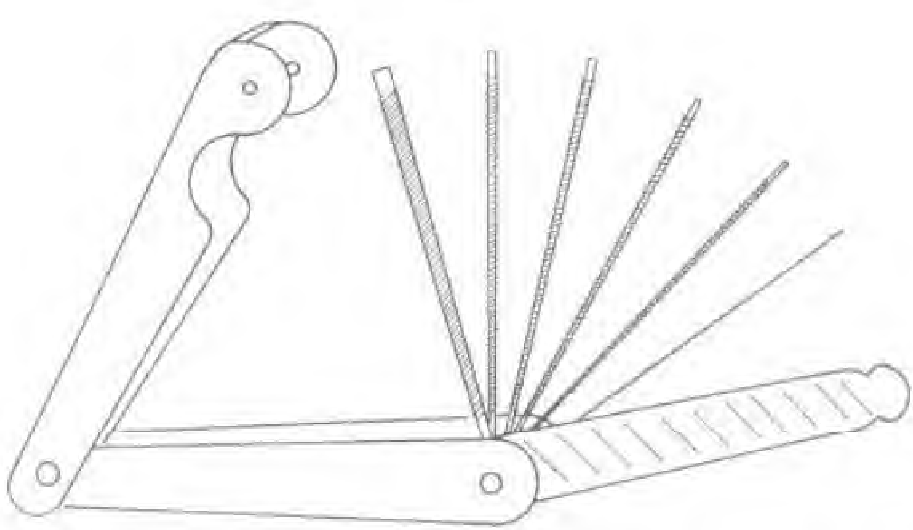
Nozzle Reamers

During use the welding flame may become distorted or forked because some spatter has got lodged inside the end of the nozzle. Nozzle reamers are a pack of ridged cleaners in a number of sizes to suit different nozzles. Select one which is a snug fit and use only as much as is necessary to restore a good flame. Too much filing will enlarge or misshape the hole, resulting in a permanently distorted flame.



Flint lighters.

Nozzle reamers



Clamps

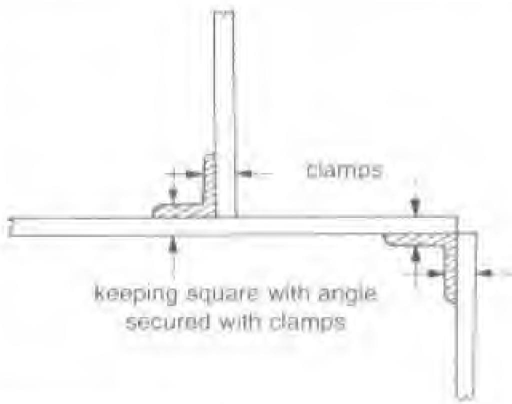
Since welding involves holding two or more pieces of metal together and heating them up, some sort of clamping system is often necessary, both to aid initial assembly and to hold the pieces in place during welding. Of the myriad types of clamp available, G-clamps and mole grips will find much use.

PREPARING THE WORK

Like many other tasks, a successful outcome is greatly influenced by the degree of care taken in its preparation. A carelessly cut component may give rise to a large joint gap which is then difficult and slow to fill. Failing to clamp pieces together may result in a good weld holding together a distorted construction.

Firstly, all new or replacement pieces are cut to size, making allowance for gaps or overlapping of joints. The metal must be reasonably clean. It is unlikely that the metal will need degreasing but it should be free of excess oil, grease, paint, soil or rust. Cleaning with an angle grinder or a pedestal grinder may be necessary if the surface is badly corroded.

The components need to be held together well enough not to move unduly when tacking or welding, and the clamp, grip or whatever you are using, must be capable of withstanding welding heat. If possible assemble the whole job, so that each component helps hold another in place during assembly and so that the appearance of the finished job can be anticipated.



Metal assembly aids

Finally, place the work in the most accessible position possible, or arrange yourself as comfortably as possible to give yourself the best possible chance of doing a good job.

Preparing the Equipment

The following sequence for preparing to weld can in some instances be varied, but it is logical, tried and tested.

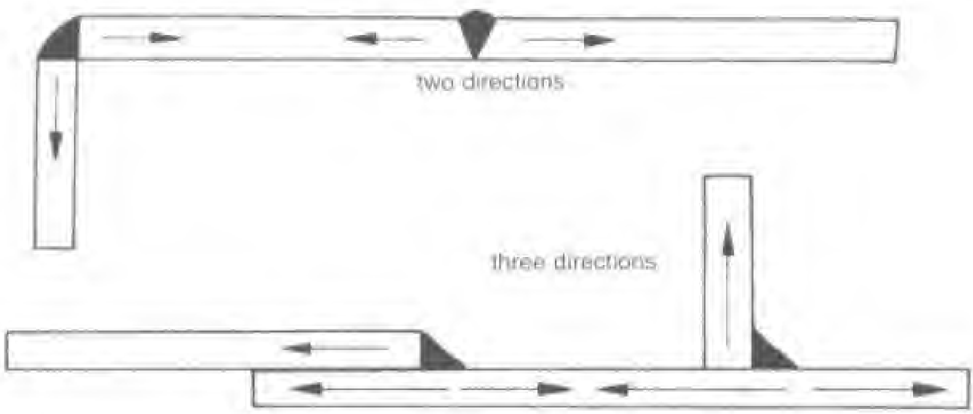
It makes sense to set up those things that can be arranged before the equipment is turned on. The following preparations fall into this category. Put on protective clothing as necessary, and obtain the following:

1. Nozzle
2. Filler wire
3. Flux
4. Means of flame ignition
5. Goggles
6. Fire extinguisher

Selecting the Nozzle

The choice of nozzle will be determined by:

1. The thickness of metal. This is the most significant variable and is the starting point in the table on page 42. Thicker metal needs more heat/larger nozzles than thin.
2. The mass of material. Two items each 2mm thick will not be welded with the same nozzle if one measures 500mm × 250mm and the other 10mm × 5mm.
3. The type of joint. An edge meeting a surface making a "T" joint will require more heat than an edge meeting an edge in the same thicknesses, because there is more metal to conduct the heat away.
4. Thermal conductivity will partly determine the ease with which a weld pool can be obtained at a particular spot. High conductivity metals like copper are difficult to melt locally until all of the metal becomes very hot.
5. The specific heat capacity of the metal makes a theoretical difference to the amount of heat required, but its effect is barely perceptible in welding.
6. The welding position will have some influence because a smaller weld pool tends



Effect of joint configuration on heat requirement

to be used when welding overhead, for example.

7. Speed of welding. A nozzle which is slightly too large may be usable providing there is an appropriate increase in speed.

8. A nozzle which is a little small may prove to be manageable providing the gas supplied through it is increased beyond the normal settings.

Whilst thickness is used as the main guide in nozzle selection, ascertaining the optimum size can only be an 'educated guess', and therefore some trial and error must be expected.

Selecting the Filler Wire

Adding filler wire is necessary in order to reinforce the welded joint, because as the edges are melted they tend to sink and be hollow. They vary in type and diameter.

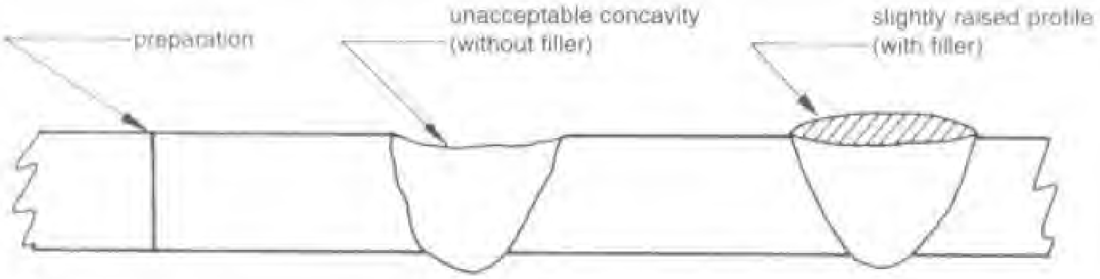
The filler wire chemical composition is matched as closely as possible with the parent metal (the metal being welded). In simple terms this means that a mild steel wire is used for mild steel, stainless steel for stainless steel and so on. Clear exceptions to this are when brazing metals other than brass and when joining dissimilar metals. Wires for welding mild steel have a thin layer of copper on the surface, simply to prevent them rusting before use. These wires are referred to as CCMS (copper-coated mild steel).

Diameters of filler wire vary from 1.2mm up to 5.0mm and are chosen to match the metal thickness as closely as possible.

Selecting the Flux

Generally a flux is not necessary because most welding involves fusion of mild steel, and this metal is peculiar in not needing any. This is because, like copper, it forms an oxide with a lower melting point than the metal itself, and the small amounts of oxide that do form can be expected to float to the surface of the weld and not spoil its strength. Most metals form a high melting point, refractory oxide and need a flux to break these down, and float them off.

Flux for fusion welding comes in powder form, of varying colour and density, and is selected to suit the type of metal being welded. Its function is to prevent oxidation of the weld area, break down any oxide which does form, and also to combine with any other impurities present. The addition of flux makes the weld pool appear cleaner and brighter, and makes it flow better; the absence of these signs indicates that more flux should be added.



Close butt joints with and without filler addition

Lighting Up

Once the initial equipment preparation is done, and the components to be welded are set up and ready to weld, a final safety check is a good idea before commencing to weld.

The procedure for obtaining a suitable flame is:

1. Turn on cylinders.
2. Adjust the working gas pressures.
3. Turn on the acetylene and ignite.
4. Turn on the oxygen and increase to produce a neutral flame.

Turn On Cylinders

The valve must be turned as slowly as possible to retard the shock loading of the regulator diaphragm. The cylinder pressure will now be displayed on one of the gauges.

Adjust Gas Pressure

This is done with each gas independently.

The cylinder pressure gauge reading when full

The pressures are set with the torch control knob open, because it will be open when in use. Wind the regulator knob in clockwise whilst watching the needle rise on the delivery pressure gauge. This will typically be set to 0.14bar, but for larger nozzles refer to the table overleaf. Turn the torch control knob off, and repeat for the other gas.

The delivery pressure gauge set typically on 0.14bar

Setting the pressure with the torch valve closed can be inaccurate and confusing. Winding the regulator knob in will cause the gauge needle to rise, but if it is wound back out the reading will not fall. At this point the reading is high, but when starting to use the torch the gas will quickly drain and there will be no pressure reading or flame at all!

Lighting the Flame

Give the torch acetylene knob about a quarter turn, allow the acetylene to purge the

mild steel thickness mm	nozzle size	gas consumption l/h	ft³/hr	gas pressures oxygen and acetylene	filler wire mm
0.9	1	28	1	2lb or 0.14bar	1.2
1.2	2	57	2		
2.0	3	86	3		1.6
2.6	5	140	5		2.4
3.2	7	200	7		3.0

system for about 2 seconds and then turn off. Repeat this with the oxygen supply.

Turn on the acetylene again about a quarter turn, allow to flow for about 2 seconds, and ignite. It should be lit near the end of the nozzle, about 25mm away from the end at most. Consider at this time where the flame is pointing as it is lit, and give it total attention whilst it is burning. If any distractions or interruptions to welding are anticipated then turn the flame off.

The acetylene supply is now increased until the flame ceases to burn with smoke. If this is done slowly then much soot and smoke is released into the atmosphere because combustion is incomplete, so learn to adjust the acetylene as quickly as possible.

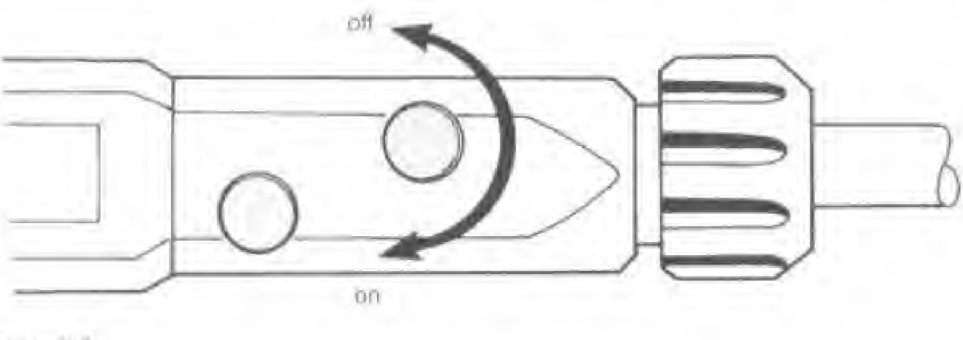
The Neutral Flame

Oxygen is now introduced into the flame which causes it to change colour from bright yellow to blue. As the oxygen supply is increased three parts of the flame become increasingly clear. At the nozzle end is the 'inner cone', about 10mm long and a very light blue. Extending around this is the 'outer cone', which is duller and less defined; it has a feathery edge. Finally there is the main body of the flame which is known as the 'envelope' of the flame.

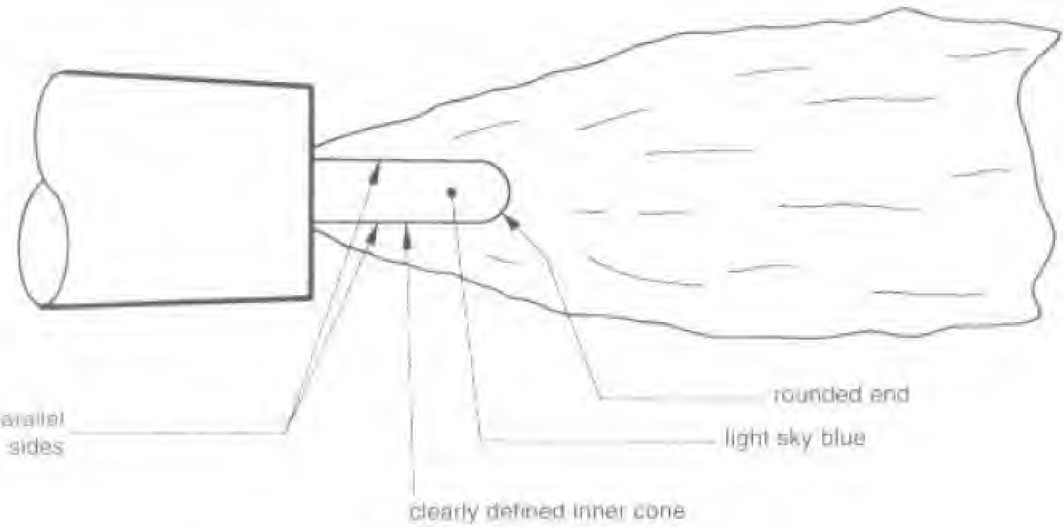
The oxygen supply is increased until the outer and inner cone merge in exactly the same place and the inner cone becomes very definable. For quality welding it is absolutely essential that this neutral flame is achieved.

The Carburizing Flame

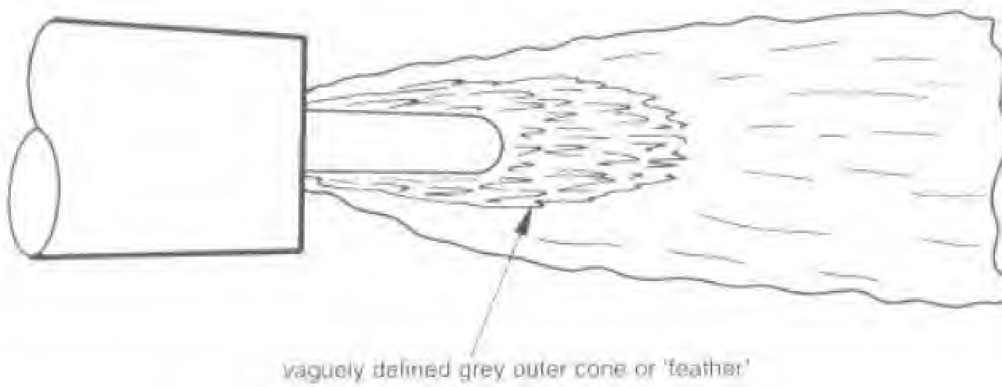
Just before the neutral flame is obtained, there is a lack of oxygen (or excess of acetylene) making what is known as a carburizing



Torch gas control



The neutral O/A flame.



The carburizing flame.

flame. This has a generally undesirable effect on steel, producing a shower of dull red sparks, and the weld pool appears scummy and difficult to melt deep into the metal.

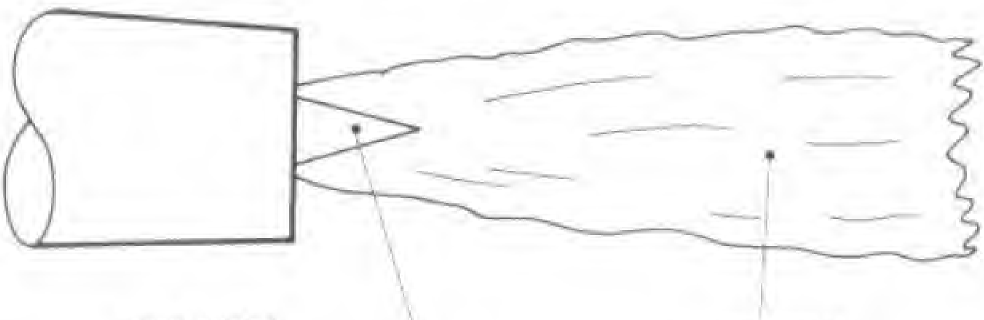
The Oxidizing Flame

If further oxygen is added to a neutral flame then it becomes an oxidizing flame. The excess of oxygen reacts with the metal to form oxide, which greatly weakens it. Using an oxidizing flame to fusion weld mild steel produces masses of bright yellow sparks and the weld pool appears to bubble and boil.

Applications of Flame Types

The neutral flame is 'chemically' neutral, that is, there are no chemical reactions between it and the weld metal. It follows that a neutral flame is used for almost all welding work.

Carburizing the weld metal – producing



An oxidizing flame

iron carbide – will have a minor effect on its strength, but it will become much harder and more brittle. Oxidizing the weld metal reduces its strength and ductility, and also makes it more brittle.

These flame types do have their particular applications, however, with carburizing being used for hard surfacing, and slight oxidizing for braze welding (see Chapter 2).

Making a Weld Bead

Without Filler

Before considering joining two pieces of metal together some basic practice in melting a weld pool and controlling it on the surface of a small sheet of steel is a a good idea.

Take a sheet at least 150mm square by 1.5mm thick; a look at the table on page 42 will indicate that a No. 2 nozzle is needed, with delivery gas pressures of 0.14bar.

Set the sheet on a fireproof surface, have goggles to hand and set up a neutral flame. Put goggles on and direct the flame at the metal with the end of the inner cone about 2mm above the surface. The angle between the torch and sheet needs to be about 60 degrees, pointing in the direction of travel.

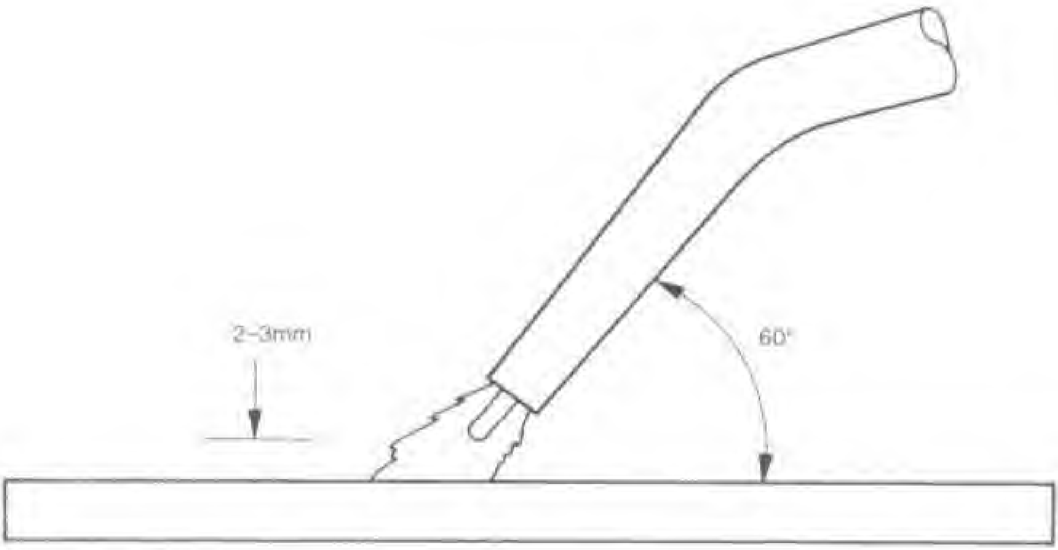
Producing a weld pool takes a little time – how long depends on the metal thickness. On 1.5mm thickness it will take about 5 seconds for the first signs of melting to appear and a little longer before the molten puddle grows to a workable size. Once the pool is 4mm wide it will be melting well and through the thickness.

Move the torch along the sheet, keeping the pool width constant. If it grows large or breaks through into a hole increase the speed of travel. If the weld pool appears to 'dry up' then slow down. This assumes of course that the torch height and angle have remained constant, as these will affect melting as well.

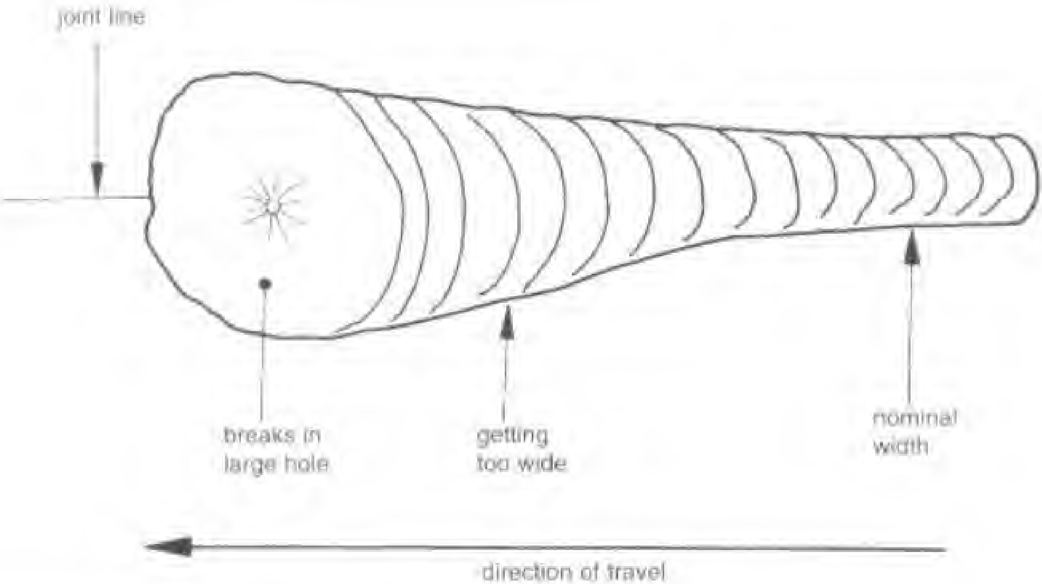
Practice should continue until fused weld beads can be made of specific and even width.

With Filler

Most welds require the addition of filler to develop full strength but at first it can be a very difficult and frustrating skill to master. Co-ordination between both hands is now



Torch angle and height

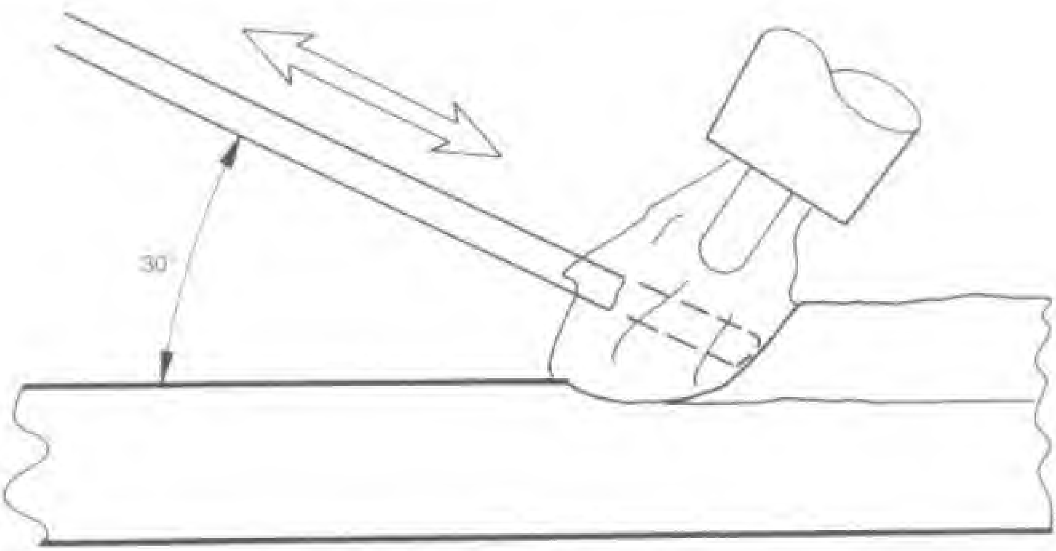


A gas bead made with too much heat

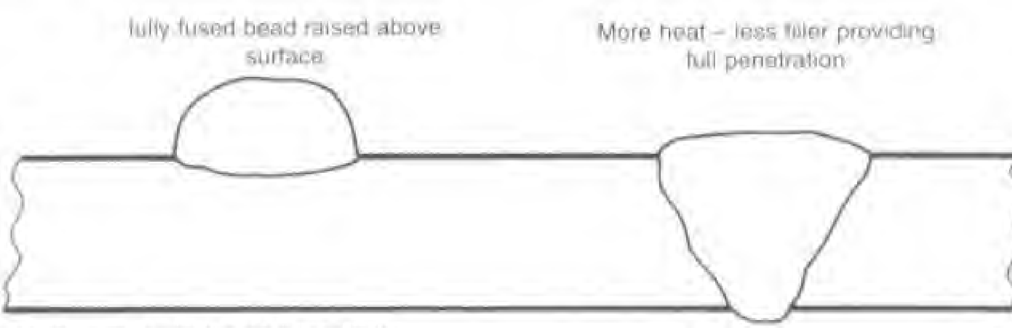
needed and a good combination of effort and patience! The wire is added a little at a time to the centre of the weld pool, which will cause it to dry up a little. The wire is then removed so that the pool can recover its size, whilst also melting new material as progress is made along the sheet. The wire end is not removed from the envelope of the flame, thus preventing it from oxidizing and also keeping it hot, and so easy to melt off when next added to the pool.

Like the fused bead exercise this should be practised until the weld profile is as envisaged at the outset. Aim to make two types of bead: (a) pronounced above the surface with a smooth semi-circular ripple and (b) melting right through the sheet with slight build-up and again with a smooth even ripple.

It is worth getting good at making beads on sheet in this way before attempting a 'real' weld. The transition to making weld joints is then quite easily accomplished with minimum wastage of material or rejection/repair of poorly welded items. Practise on a range of thicknesses, using different nozzles and filler wire sizes.



Adding filler wire



Beads on plate with and without full penetration

Effect of Gas Velocity

Having lit the flame in the prescribed manner it may be found that a little more or a little less heat would allow the metal to be welded at a more comfortable speed.

If progress is somewhat slow then each gas can be turned up a little to supply more heat. Turn up the acetylene to produce a small outer cone, then the oxygen to return the flame to neutral. Doing this not only increases the amount of gas leaving the nozzle, effectively turning a No. 3 nozzle into, say, a No. 3.5 or 4, but also increases the speed of the gas. The limit to this increase has been reached when molten metal, as it is formed, is blown about or pushed through the joint.

If progress has to be fast because the metal is melting too well then the gas supply can be reduced (oxygen first) to allow more time to control the weld pool. Too much reduction in the supply – too low a gas velocity – produces a 'soft' flame, which gives rise to backfires (explosions) at the weld pool.

Causes of Backfires

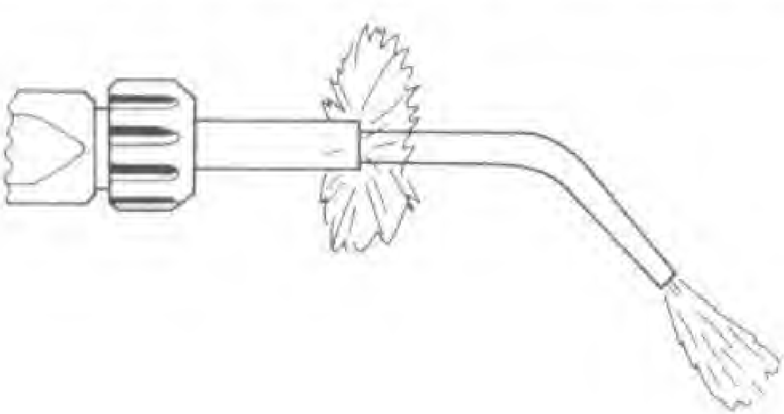
Backfires are not an inherent part of gas welding. They can be practically eliminated, removing much of the frustration, and some of the danger, from the welding process. They are explosions which occur at the weld pool/nozzle end as a result of:

1. Gas velocity being too low.
2. Inner cone touching molten metal.
3. Molten end of filler wire passing through inner cone.
4. Nozzle leaks because it is not seated properly.
5. Nozzle end being partially blocked.
6. Welding flame oxidizing.
7. Nozzle being overheated.

Of these the first four are by far the most likely causes. The cause can be difficult to detect when a number of factors are each slightly wrong, for example when the flame is both a little close and a little soft.

Causes 2 and 3 show that the inner cone and molten metal tend to react when in contact.

Nozzles leak because either they have not been hand tightened enough, or because the end is damaged in some way. Seating surfaces can be restored with very careful sanding, whilst ensuring that the end remains square with the nozzle axis.



Gas explosion at the nozzle seat.

Blocked nozzles are cleaned with nozzle reamers, and periodically the tip should have the accumulated spatter removed. The nozzle will not overheat normally, but this can happen when working in an enclosed corner where the flame plays back onto the nozzle.

Shutting Down Procedure

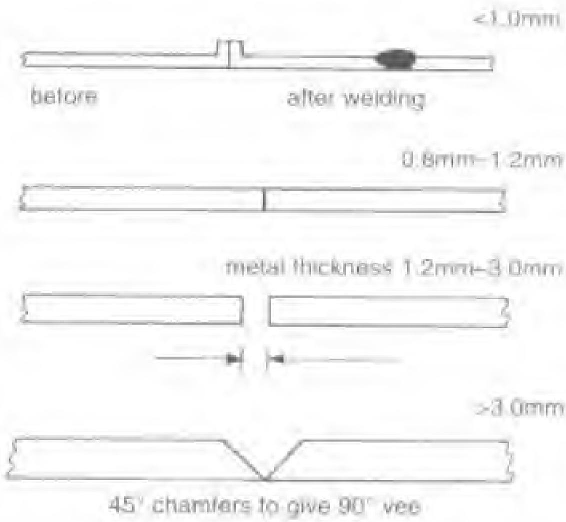
On completion of welding or when one of the cylinders is empty, the equipment must be shut down correctly. It is very bad practice to leave it turned on for prolonged inactive periods. The procedure is similar to setting up, only in reverse.

1. Turn off each of the gas cylinders.
2. Open each control knob on the torch and allow the gas to drain completely from the system. Care must be exercised in discharging unburned gas into the air at this time. As the system drains the cylinder pressure gauge will slowly drop to zero, followed by the delivery gauge falling to zero. All components are now at atmospheric pressure and therefore in a relaxed state.
3. Unwind the pressure adjustment knob on each regulator, to relax the load on the diaphragm and springs.
4. Close the torch control knobs.
5. Wrap up hoses and store equipment away.

MAKING GAS WELDED JOINTS

Butt Joints

A joint between the edges of two pieces of metal in the same plane is known as a butt joint. From the table below it can be seen that the preparation will depend on the metal thickness. Thin material is welded with the edges touching, thicker material with a gap between the edges and thicker material still requires chamfered edges which form a V when placed together. Use of gaps and Vs enables melting to occur easily at the bottom of the joint without needing an enormous weld pool for this to happen.



O/A butt weld preparations

Tacking

Most welded assemblies need the components of the fabrication to be 'tacked' together before welding commences. Tacks are short lengths of weld which both aid assembly and keep the metal together during welding.

In mass production situations formulae can be applied to the size and frequency of tacks, but for manual 'one offs' experience is the best guide. Tacks will tend to be made longer but less frequently as the metal thickness increases.

A tack welded assembly

Making a Close Square Butt Joint

Align the joint edges without a gap on a flat firebrick surface. Make a small tack in the centre of the length noting that as this is done the metal will expand and possibly warp. If the metal is now misaligned at the point of tacking, pick it up with grips and place it on a solid metal surface. Strike with a hammer directly on the tack whilst it is still hot to bring the pieces back into the same plane.

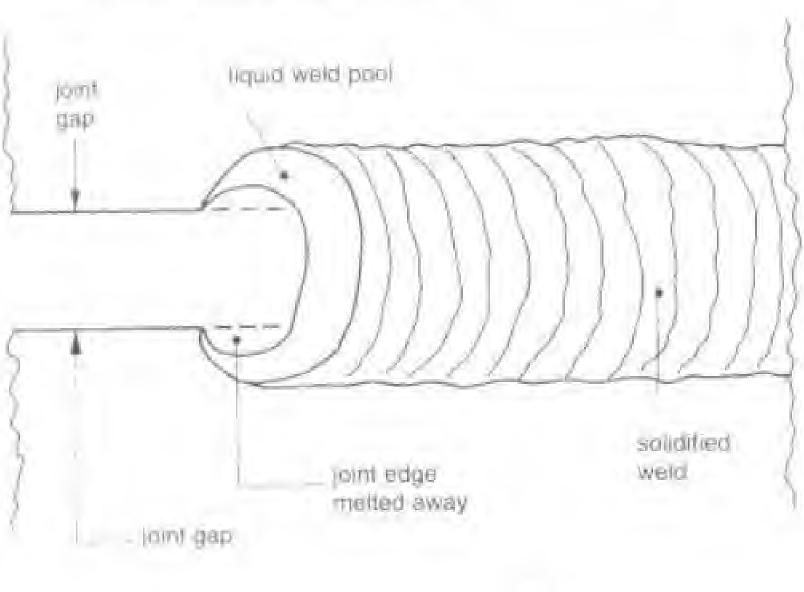
Place the second tack about 40mm away and work outwards in each direction to the end of the joint. As tacking progresses it will be necessary to keep realigning the edges to keep them flat.

Welding is now simply a matter of repeating the bead on plate exercise, with the bonus of having a joint line to follow, which should keep the weld straight. A full-strength weld is often not necessary, but where it is needed the weld must fuse through the full thickness. This is ensured by melting a pool, continuing to heat until it sinks a little, but without collapsing (tricky!), then adding filler and moving on to repeat the cycle.

Making an Open Square Butt Joint

The joint is set up with a gap between the edges, either of necessity because the material was cut inaccurately, or deliberately because it is preferred. With a gap equal to the metal thickness it is easier to melt to the base of the joint and see clearly that this is happening, but the technique is initially difficult to master.

The flame is directed at the gap, without movement, until the edges melt away evenly. Filler is added to produce a molten bridge across the gap and a molten 'key-hole' shape is created.



The open butt welding 'key-hole'

This key hole is traversed along the joint, ensuring that it does not grow too large through lack of filler or slow welding speeds, and that the key hole does not fill in because too much filler has been added or the weld has advanced too quickly.

Making Single V Butt Joints

Steel over 3mm thick is likely to be joined with an arc welding process but gas welding still has its place, for example in site welding of small diameter steel pressure pipes.

The edges are chamfered at 45 degrees and placed together to produce a 90-degree V with a small gap. Welding may be possible in one pass, but splitting it into two passes offers better control. Concentration on the first pass can be devoted to penetrating the bottom of the V properly and evenly, and on the second pass to fusing the first run and filling up the V evenly.

Making Corner Joints

Most metal construction involves welding into a 90 degree corner, and this is known as fillet welding. Fillet welds can be made on the outside or the inside of corner joints, or into the corner of Ts or lap (overlapped) joints. The approach to each will vary.

Outside Corners

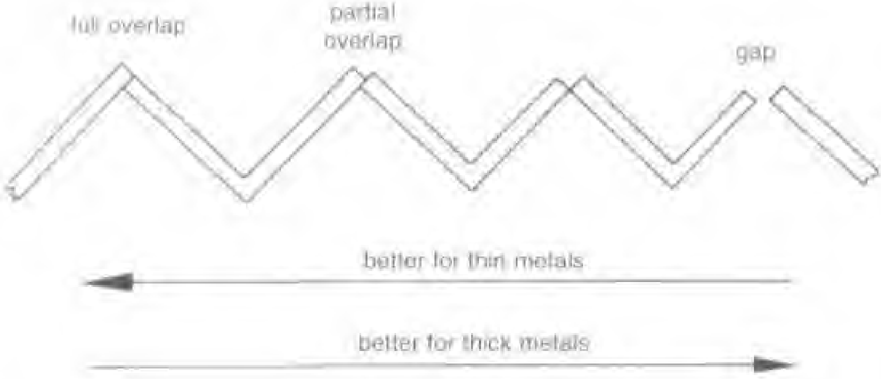
When learning to weld these are good joints to start with being fairly easy and satisfying to make.

The joint edges may vary in relation to each other from being fully overlapped to having a gap, which has a great effect on penetration. For full strength the weld must fully fuse through the thickness and this will be difficult on thicker metal if the edges are overlapped. Conversely very thin metal is difficult to control with a gap and easier to weld when overlapped.

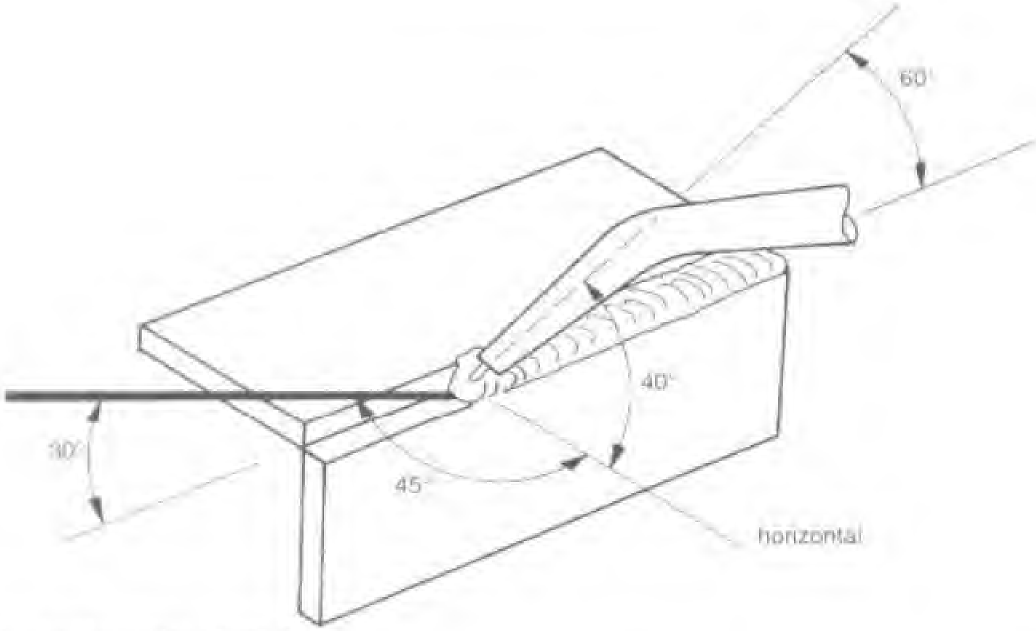
Attention must be paid to ensuring that all of the joint surfaces melt and then that sufficient filler is added to build up an effective weld, typically one with a quadrant cross section.

Inside Corners and T Fillets

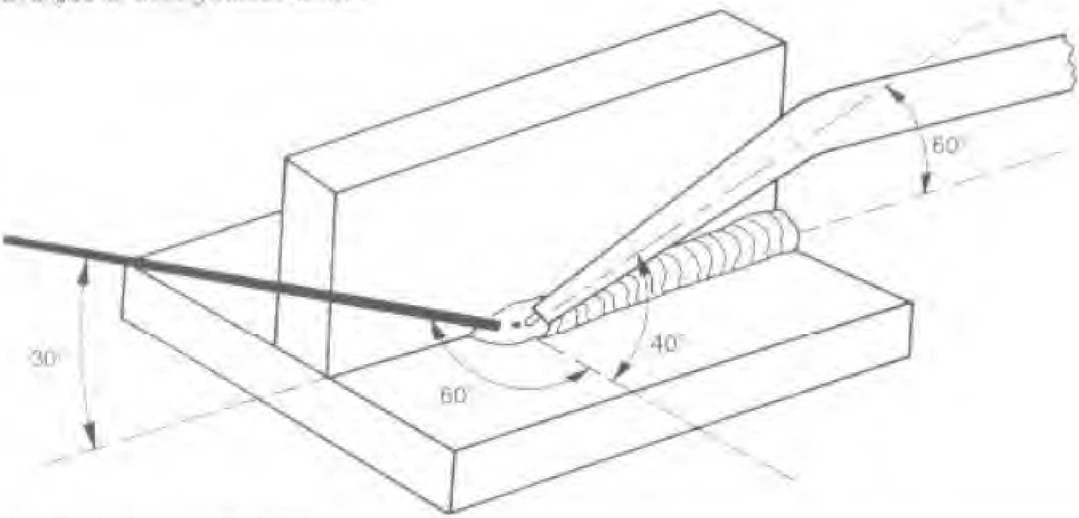
Each side of the joint can be expected to melt evenly when producing outside corners and butts, but where an edge meets a surface the edge will tend to melt much more quickly because it dissipates heat in only one



Outside corners



Torch angles for welding outside corners



Torch angles for welding fillet joints

direction. This tendency can be offset by directing the flame rather more at the surface than at the edge, making small adjustments to position and angle until each side of the joint melts evenly.

The heat supplied to these joints is being taken away in three directions and therefore a larger nozzle is likely to be required than for butt welding in the same thickness.

Lap Joints

Like the T fillet some experimentation is necessary to find a personal optimum angle/position. The metal can be addressed

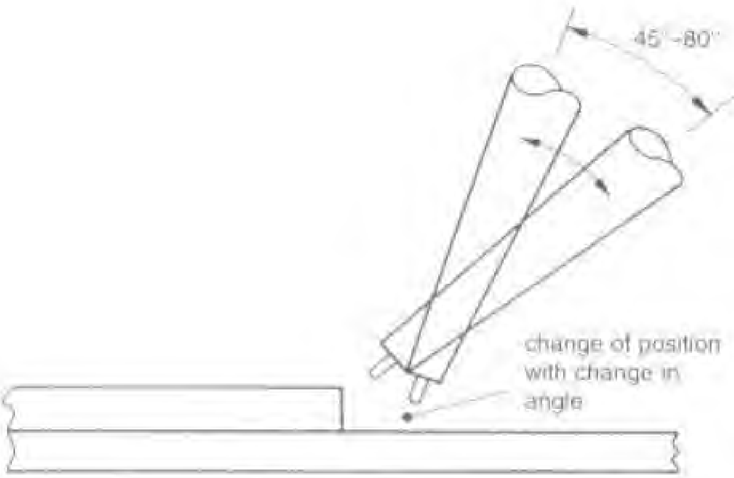
guite squarely, aiming mainly into the lower surface and taking in the edge at the side of the weld. The other extreme is to direct the flame at 45 degrees, melting much of the edge away and fusing this onto the lower plate. Taking up a position midway between these angles is likely to prove the most satisfactory option.

Other Joints

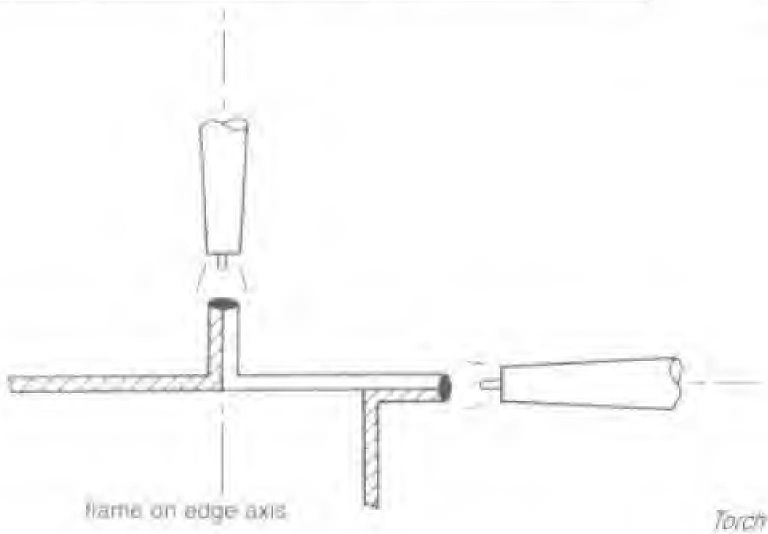
Most welding work is comprised of the types of joint above but there are of course others.

Edge welds are made between the edges of a steel 'sandwich'. These are done most easily and smoothly by simply fusing together without filler.

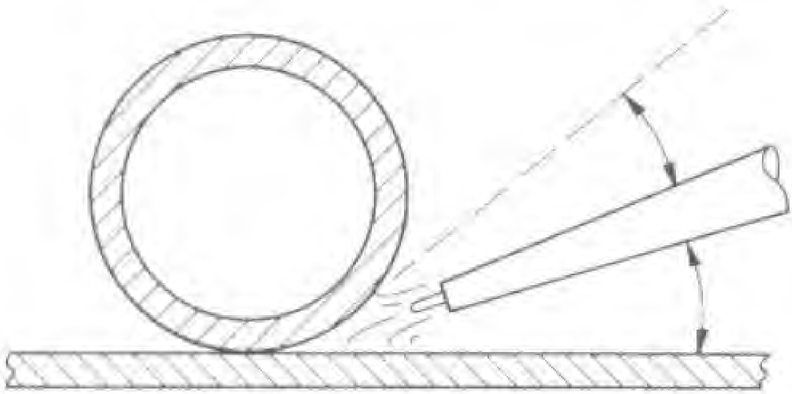
Welds like the one in the diagram opposite between a pipe and sheet are not categorized, and have to be treated on a one-off basis. The rule of thumb, for any process, type of joint or position, is that the joint surfaces are bisected with the welding head. An allowance may then be made for gravity where it tends



Torch angles for welding lap joints.



Torch angles for welding edge welds.



Torch angles for welding pipe to plate.

to pull the weld out of shape, and for dissimilar thicknesses where one side of the joint heats up faster than the other.

Cooling Rates

Cooling welds are potentially hazardous during the period when they have cooled down from red-hot and do not appear hot, but are still capable of burning bare skin. This is a lesson novice welders learn the hard way, and probably many times before sufficient caution is developed.

Where a number of people work together this caution must be extended to other welders' work too, and marking the job as HOT with chalk will help reduce accidents.

It would seem logical to quench the work immediately after welding both to make it safe and to enable further operations on the work to commence. The cooling rate, however, has a profound effect on the mechanical properties of the metal. Fast cooling rates are used on certain carbon steel components to make them hard and this is accompanied by an increase in brittleness. Quenching welded joints in water is unacceptable because they would become hard and brittle.

Exceptions are practice situations where it does not matter, and some cases where the heat being conducted from the weld through the metal might damage items like seals or bearings. Here the advantages of quenching outweigh the disadvantages.

Gas Welding Variables

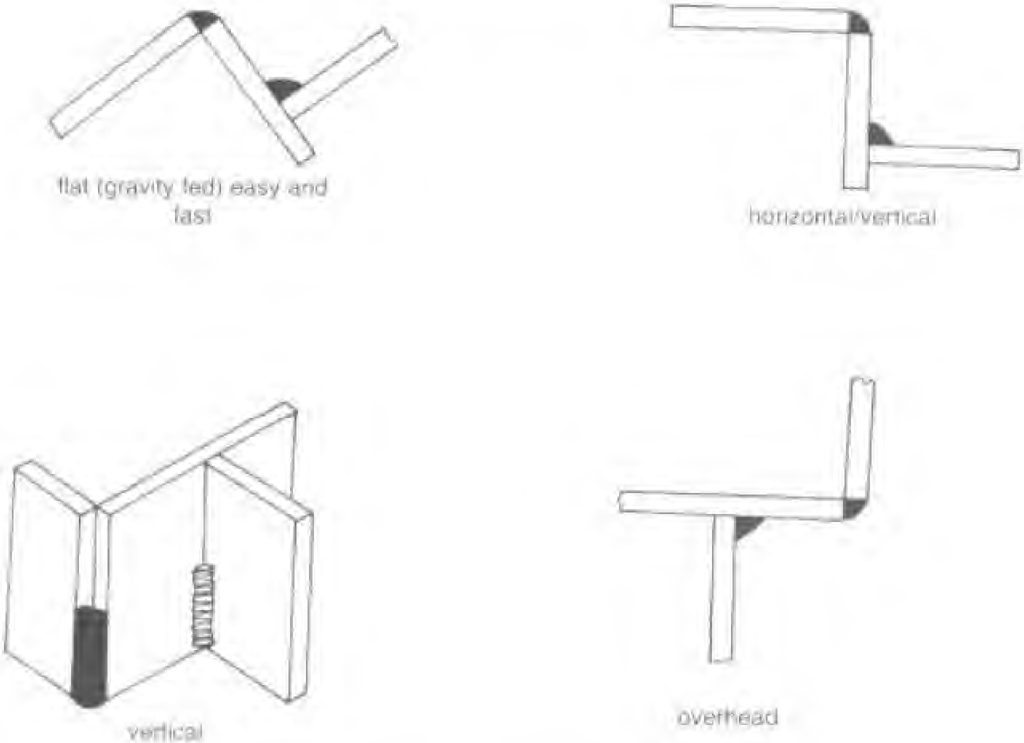
If a weld on one occasion is done well, and on another it is not as good, then clearly some aspect of welding has changed. These possible differences or variables are considered below. Consistency, or quality assurance, is obtained by standardizing variables and thus removing their effect.

Size of Material

As the thickness and mass increases, more metal preparation is necessary, the weld pool takes longer to form and welding speeds are slower. Theoretically any thickness can be welded, but metals between 0.9mm and 2.5mm can be welded with a reasonable combination of ease and speed.

Position of Weld

Whenever possible the joint should be placed in the flat (gravity fed) position.



Welding positions

Welding vertically or overhead is both slower and more difficult.

Type of Material

All the common engineering metals can be gas fusion welded with mild steel being both the most common and easiest. Cast-iron, brass and stainless steel are more difficult, and aluminium requires great gas welding skill, but the metal with the poorest weldability is zinc, which is commonly used as the base of cheap, mass-produced castings like carburettor housings.

Type of Joint

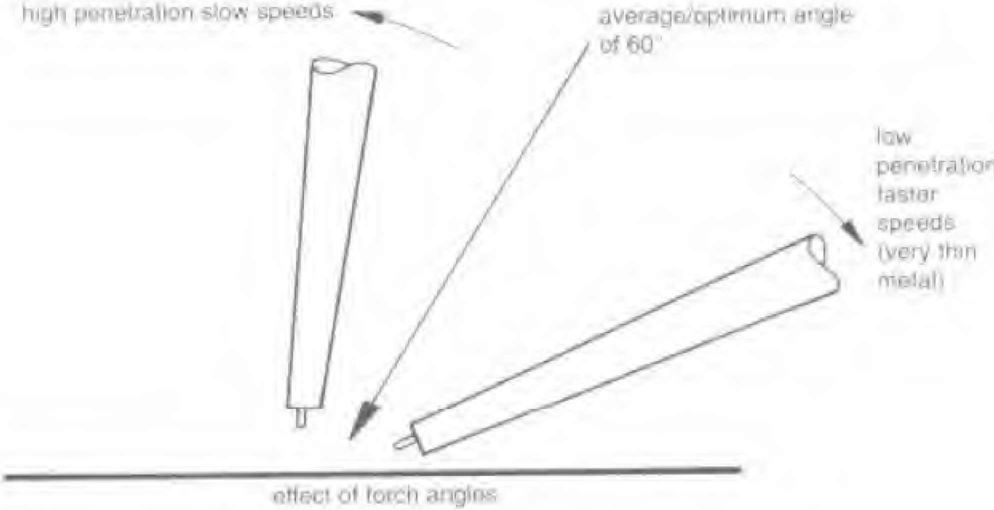
Corners and butts (edge to edge) require less heat, or can be welded faster than fillets and laps (edge to surface).

Torch Angles

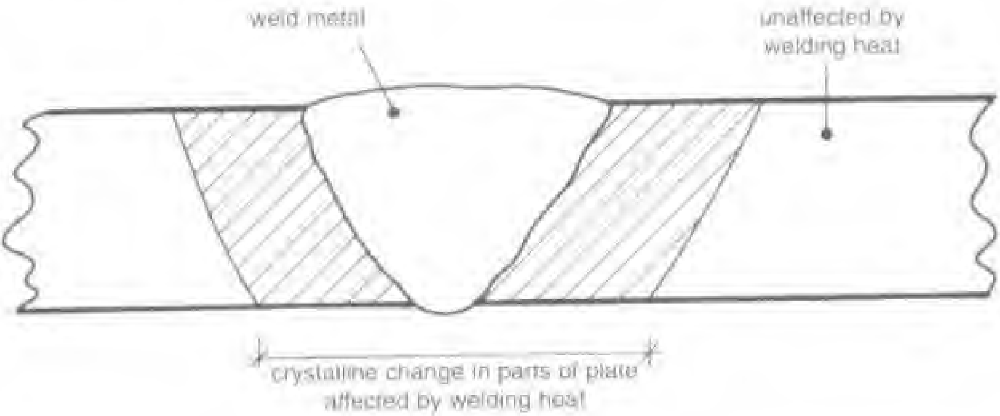
A shallow torch angle heats the metal ahead and speeds up welding but makes it more difficult to penetrate into the metal at the welding point. This can be useful on very thin metal which can be penetrated too easily! Steeper angles penetrate better.

Speed of Travel

Gas welding is inherently a slow welding process. If the speed is too slow then the weld puddle will grow very large and difficult to control. Excess heat impairs the crystalline structure of the weld because the crystals, or grains, grow unduly large. The neighbouring metal, known as the 'heat-affected zone', or HAZ, also suffers grain growth and the resultant reduction in mechanical stability.



Effect of varying angles on speed/penetration.



The heat affected zone.

Fast welding speeds will tend to underfuse or underpenetrate the metal. More skill is needed to work at the faster pace, but the lower heat input will produce less distortion of the material.

Filler Wire Angles

Filler wire is added most easily when it is in line with the nozzle and forms a right angle (90 degrees) with it.

Filler Wire Size

Thin wires produce smooth welds but are either ineffective or have to be added very quickly and are then rapidly consumed.

Thick ones tend to produce 'lumpy' welds and absorb much heat, which in turn slows down the welding speed. This can be useful on thin metal which is proving difficult to control.

Technique

Since welding is a manual skill there is no universal agreement on precisely how to execute any particular task. Various movements of the torch and filler wire are recommended by some authorities, and these differing approaches will vary the outcome.

For consistency and ease variables must be minimized and therefore the best movement of the torch is progressively forward in a straight line; similarly the filler is moved straight into and back from the weld pool.

The technique described up to now is the 'leftward' technique used by a right-handed person – welding from the right towards the left of the joint. A left-handed person would weld towards the right, so the leftward technique essentially means that the flame points in the direction of travel and is preceded by the filler wire.

Welding of metal over 5mm thick can be greatly speeded up by using the 'rightward' technique but the prevalence of arc welding for such thicknesses has outdated this in most cases.

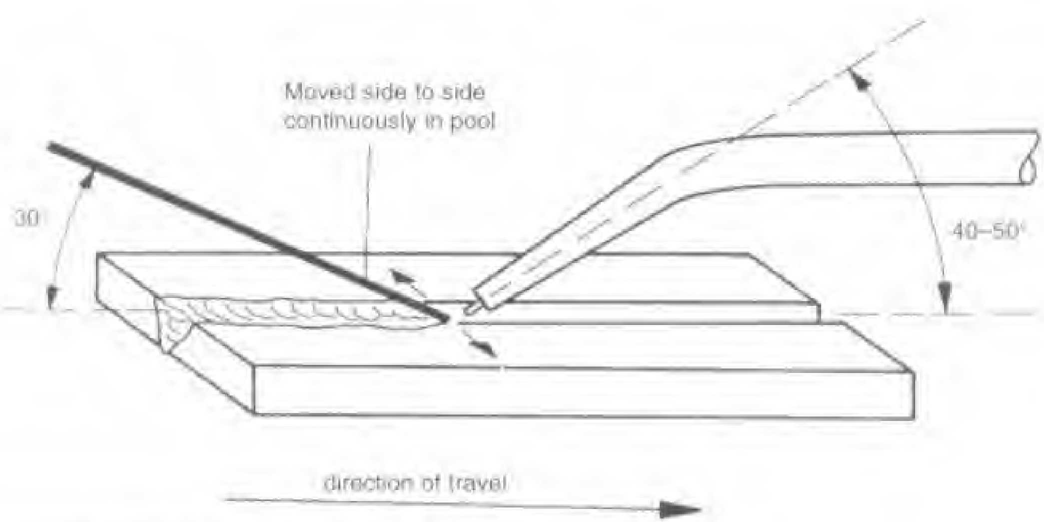
In all welding operations the weld quality will be influenced by the skill and confidence of the operator and the ease and comfort with which the work is approached.

Other Factors

Nozzle size, edge preparations, pressure settings and flame gas velocity will each influence weld quality as discussed earlier.

OXY-ACETYLENE EQUIPMENT – SAFETY DEVICES AND PRECAUTIONS

This section should be read and its contents understood before starting to use the equipment for any purpose whatsoever. It is presented at this point rather than the start of the chapter because it is necessary to be familiar with the equipment and how it functions before the safety devices it contains and safe usage can be fully appreciated.



Torch and filler angles for the rightward technique.

Some precautions have already been considered and are listed here for reference but not expanded on further.

Safety considerations can be sub-divided into a series of Dos and Don'ts. There are also those things that a mature operator with a basic grasp of engineering principles could be expected to know, such as avoiding any heating of cylinders, while other aspects require more specialist knowledge – for example, knowing that lubricating an oxygen threaded connection could lead to a spontaneous explosion as the joint is tightened.

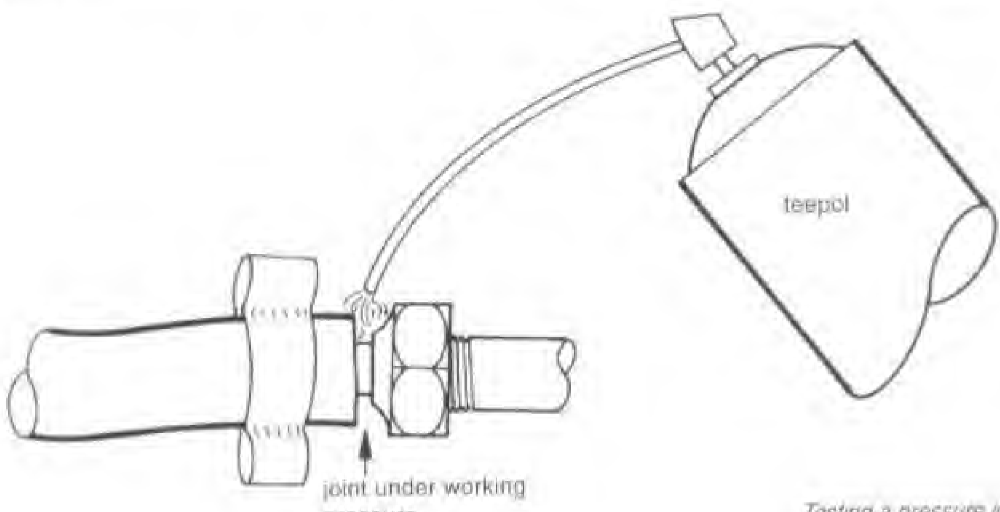
If you want to live long enough to become a good gas welder do not ignore this section!

Cylinders

1. The acetylene cylinder may have a safety relief valve at the neck or in its dished base. If either is found to be leaking then take it outdoors, drain it safely, inform the supplier and obtain a free replacement. Make no attempt to repair it.
2. Store and use acetylene in an upright position.
3. Where a quantity of cylinders are stored.
   a. Keep different types of gas apart.
   b. Keep full and empty cylinders apart.
4. Keep oxygen cylinders and all fittings clear of oil and grease.
5. Avoid any heating of cylinders.
6. Do not open cylinders more than is necessary.
7. Keep secure with restraining chain/strap.
8. Do not 'churn' cylinders (roll by hand) for great distances – use a cylinder trolley.
9. Do not use as rolls.
10. Close valves on cylinder when:
   a. Moving cylinder.
   b. Work is finished.
   c. Cylinder is empty.

Regulators

1. 'Sniff' the cylinder before mounting the regulator.
2. Slacken the pressure adjusting screw when work is finished, or when changing cylinders.
3. Only use regulators that are:



Testing a pressure joint with teepol.

a. Designed for the gas being regulated.
b. Designed to handle the full cylinder pressure.
c. Have gauge needles that work and zero properly.

4. Ensure no gas connections leak, test with Teepol.
5. Make no attempt to repair regulators, but get them service exchanged.

Flashback Arrestors and Hoses

1. Flashback arrestors extinguish flashbacks and cut off the supply when the pressure changes.
2. Hoses are colour and 'thread' coded.
3. Hoses contain a hose-check valve at the torch end.
4. Separate bonded hoses before use.
5. Use approved hose connectors for repair joints.
6. Copper and 70 per cent-plus copper alloys form explosive compounds when in contact with acetylene. Avoid their use in repair work.

Using the Equipment

1. Remove all flammable material from the vicinity of the welding area.
2. Ensure fire extinguisher is to hand and operational before commencing work.
3. Whenever possible have a 'watcher' or someone on hand who can act quickly in the event of an accident. When working as an employee this is a legal requirement.
4. Give full attention to the flame when it is running, if you are distracted or something needs to be fetched, turn it off.
5. Consider the consequences of producing and/or igniting fume.

Coated Metals

Materials coated with paint or plastic or metals like chrome or cadmium can produce fume which may be toxic or simply irritate the lungs and skin. Of these zinc is a classic example: if inhaled in gaseous form when welding galvanized steel it will produce nausea and flu-like symptoms. Remove the coating first or use effective fume extraction.

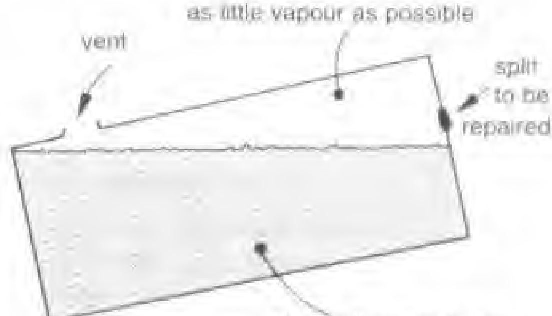
Fuel Tanks

Tanks which have been empty for years can still explode after welding has been under way for some time. The welding of vessels has been the cause of many tragedies as a result of either ignorance or bravado.

Always have the vessel steam cleaned first and continue the operation until the outside has felt warm for about 10 minutes. This is necessary regardless of the size of the vessel, or what it is thought to have contained.

Then fill with water, allowing the vessel to vent through one of its inlets/outlets whilst also keeping the welding area to the top so that welding is not retarded by the water.

Finally, remember that you do not have to take on the task – is it really worth doing?



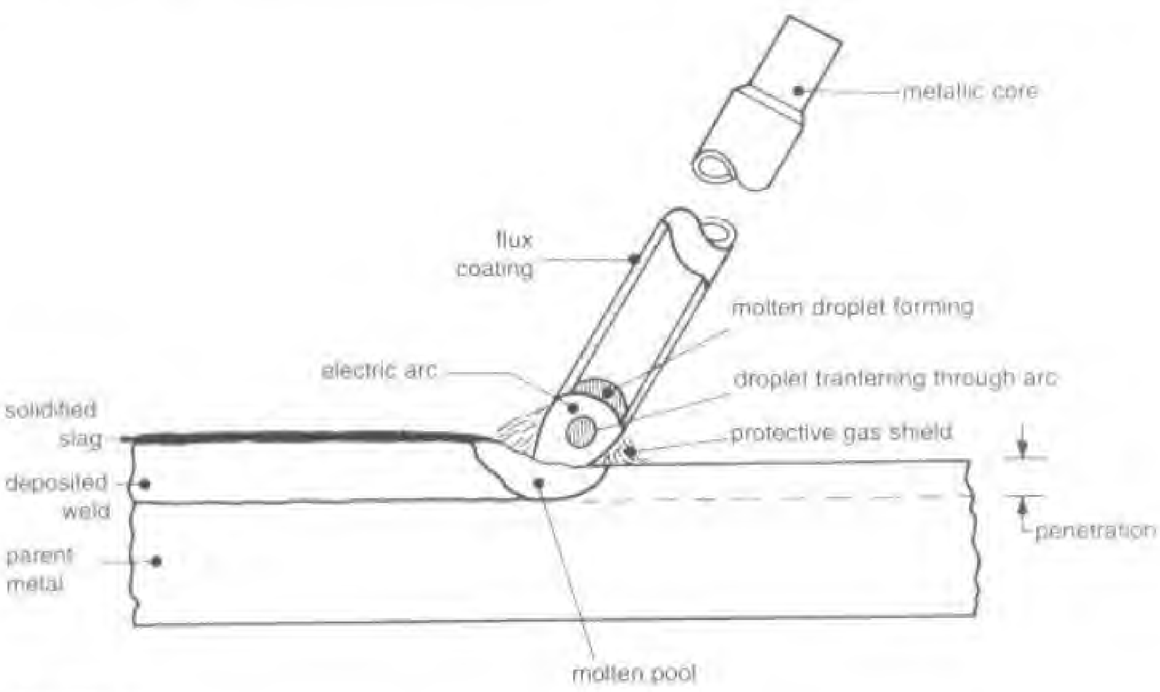
Vessel filled with water to make safe.

4 MANUAL METAL ARC WELDING

Manual metal arc (MMA) welding was the first of the many welding processes using an electric arc as a heat source, and despite having conceded its prevalence to MIG welding it is still widely used. It is favoured particularly for work requiring a combination of high quality and good deposition rates, such as boiler work, and also for site work because it has good mobility and tolerance of adverse weather conditions.

The technique is known as shielded metal arc in America and in Britain historically has simply been known as 'arc' or 'electric' welding. The latter terms proved too general but the term 'stick' welding remains a common substitute for its full name.

The 'stick' is a piece of solid drawn metal rod which is coated with a flux. An electric current is passed through the rod, jumps a small gap to the metal being welded and continues its path back to the welding power source. As the electric current crosses the



The MMA arc

gap it generates enough heat to melt the electrode and the surface of the metal. The electrode end is propelled by electrical force to the melting metal surface, where it mixes and builds up as the weld bead.

The flux coating on the end of the rod also melts and protects the metal whilst it is molten. It solidifies to become a slag and continues to protect the weld metal as it cools.

THE WELDING CIRCUIT

The following components are the essential features of the manual metal arc welding circuit.

1. Source of energy
2. Welding plant or set
3. Welding lead
4. Electrode holder
5. Electrode
6. The arc
7. Work (metal to be welded)
8. Welding return lead
9. Welding earth

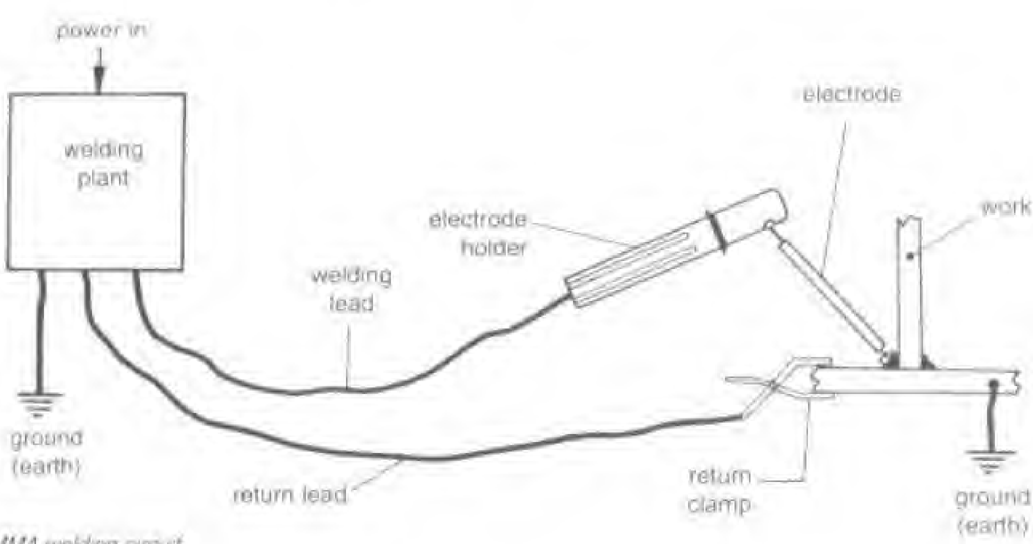
Source of Energy

Most welding sets operate off mains electricity from the national grid. Smaller ones generally run on a single phase supply – about 240V – and find use either in light fabrication or in DIY work. Larger sets require a three phase supply – about 400V – and are more economical to run. These are likely to be used in fixed industrial situations.

Other welding sets are powered by a diesel or petrol motor and find most application in site work, where mains electricity may not be readily available.

Welding Sets

The welding set must be capable of supplying a continuous current, which can be adjusted to suit various sizes of electrode, at an open circuit voltage of between 50V and 100V. There are a number of types available,



The MMA welding circuit

which vary in their energy requirement, type and amount of current delivered, open circuit voltage, duty cycle, and cooling mechanism.

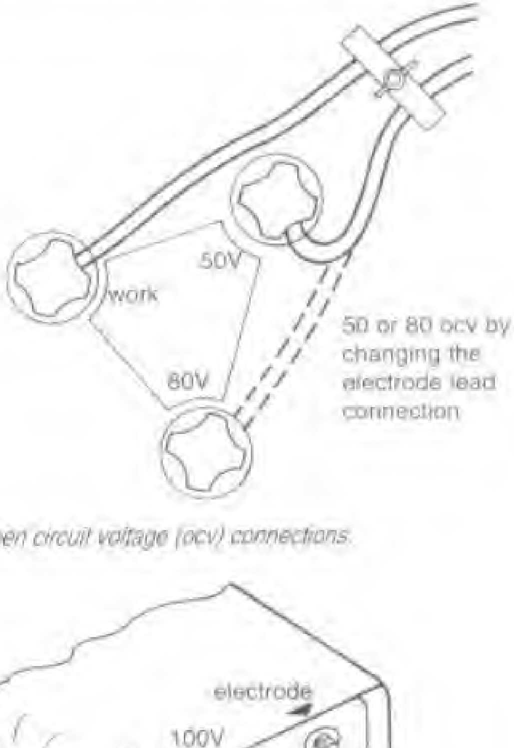
Output Current

The 'size' of an MMA set is determined by its maximum current output in amps (amperes), rather than its physical size necessarily. The amperage available will determine the largest electrode size which can be used and in turn the rate at which weld metal can be deposited. This is the main yardstick in selecting welding sets, which start at 100A, with other common sizes being 140A, 180A, 200A, 225A and 250A.

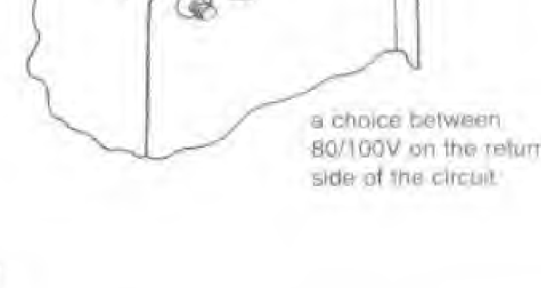
MMA welding sets from a DIY to a large 'double operator' set.

Output Voltage

This is measured by connecting a voltmeter between the electrode lead terminal and the return lead terminal, which will read 50V, 80V, or 100V. Since amperage output is the main selling point, and power is a product of amperage and voltage, manufacturers of small welding sets keep the voltage low in order to maximize the current potential. Sets with an amperage of 140A have 50V ocv (output voltage), with larger ones offering a choice between 50 and 80V, and ones above (say) 225A, a choice between 80 and 100V.



Open circuit voltage (ocv) connections.



OCV selection is made by choosing one of two return lead terminals, with the highest current being available on the lower voltage range. The effect of this 'striking voltage' is considered later.

Duty-Cycle

Although larger sets may never be used at maximum output they last longer and can be used continuously, whilst a smaller set supplying the same current at the top of its range would need to be 'rested' – allowed to cool down – frequently.

The proportion of the time that a set can be used at given current levels is known as its 'duty-cycle'. This is expressed as a percentage and the manufacturer's recommendations, possibly for various current outputs, will be found on a plate on the machine. If the duty-cycle of a 250A welding set is 70 per cent at 180A, then when used at 180A its maximum use should be for 7 minutes of continuous welding followed by 3 minutes of rest.

Type of Cooling

Smaller welding sets are air cooled, which in practice means that they heat up in use. Overheating is prevented by thermostatic control, which in turn precludes heavy or continuous use.

'Turbo' models contain a cooling fan which enables them to be used for longer periods than conventional air-cooled models.

Oil-cooled welding sets have their windings immersed in oil, which greatly inhibits internal heating. Their duty-cycle is much better than air cooled types', but being heavier they are less portable. They are not as flexible either, because they are likely to need a three phase electrical supply.

Welding Transformers

These are the least expensive type of welding set, require negligible maintenance, and a mains electricity supply. They transform mains electrical voltage, in this case reducing it from 240 or 400V to (typically) 80V across the output terminals. There is an inversely proportional increase in current in the secondary (welding) side of the circuit, so current entering the set on the primary side is low but on the output side is high enough to melt electrodes.

Welding Generators

As their name implies these are self-contained units which generate welding current and thus dispense with the need for mains electricity. They are powered by either a petrol or diesel motor and are typically used for site work.

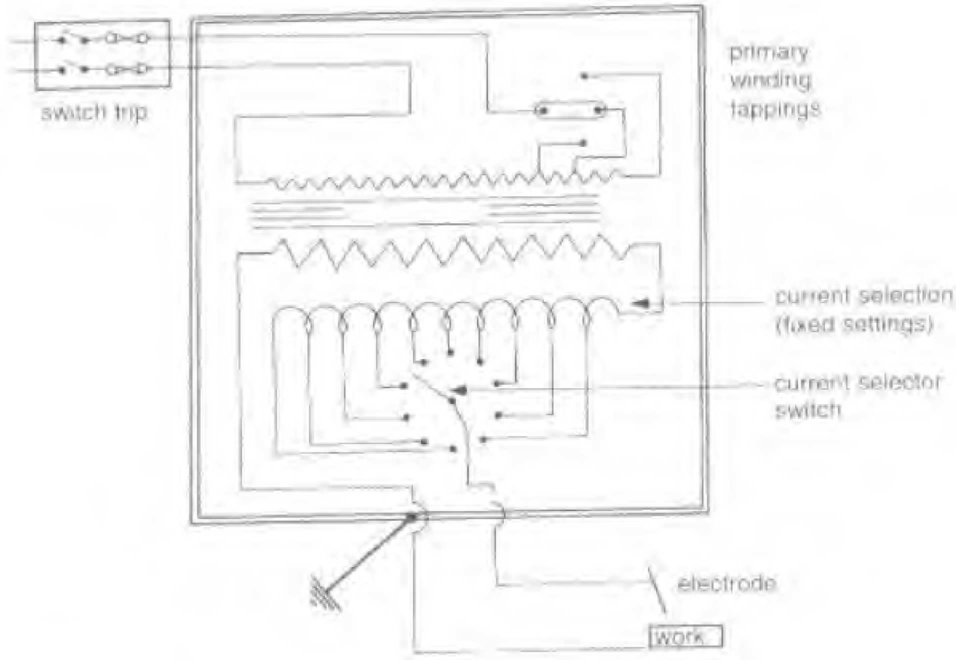
The current output can be either DC (direct current) or AC (alternating current). AC models are more prevalent because the output voltage needs only minor transformation in order to supply auxiliary power for 110V equipment like drills and angle grinders.

Welding Rectifiers

These solid state (no moving parts) pieces of equipment rectify the mains electricity supply, that is, change AC current into DC. Their use simply as a rectifying unit is as the power source for MIG welding. When used for MMA welding they are part of a set which offers a choice of either AC or DC, such as a transformer/rectifier set, and which is likely also to have TIG welding capability.

Inverters

A relatively new development in arc welding



Schematic arrangement of a welding transformer.

power sources, these change AC mains electricity into DC welding current, but are superior to rectifiers in that they are more portable (have a higer current output to weight ratio), and by the efficiency and very close control of the welding current.

Welding and Return Leads

The function of these leads is to carry welding current from the welding set to the electrode holder and from the work or bench back to the set. The latter lead is often incorrectly referred to as the earth but is properly called the return lead, because this is literally its function.

The welding lead in particular needs to be flexible in use, which is achieved by using 'thousands' of copper wires each a few thou in diameter.

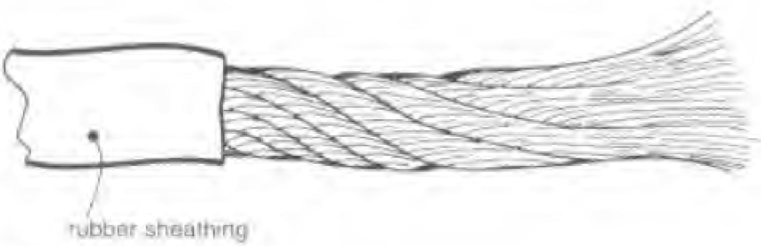
A rubber sheathing insulates these conductors to prevent electrocution or loss of power to the welding arc.

Electrode Holders

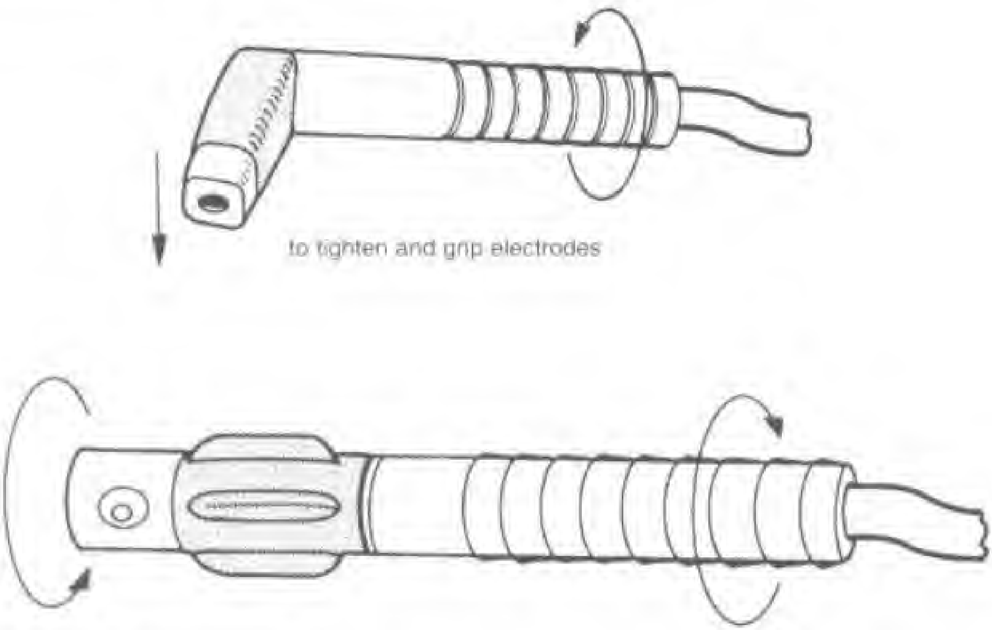
Holders grip the electrode end, transferring current from the welding lead to the electrode, and enable the electrode to be directed at the work in an appropriate fashion.

Handles vary in material, texture and diameter but will grip the electrode in one of two ways. One type has spring loaded jaws, opened by squeezing the handle or a trigger on it. These enable fast electrode changes but do rely on the integrity of the spring. The second type has a twist grip, which brings the holder head down closing the electrode port.

The choice is a matter of personal preference, and it is worth giving some thought to



Stranded end of a welding lead.



Twist grip electrodes holders.

since it will affect operator comfort/confidence.

The Electrode

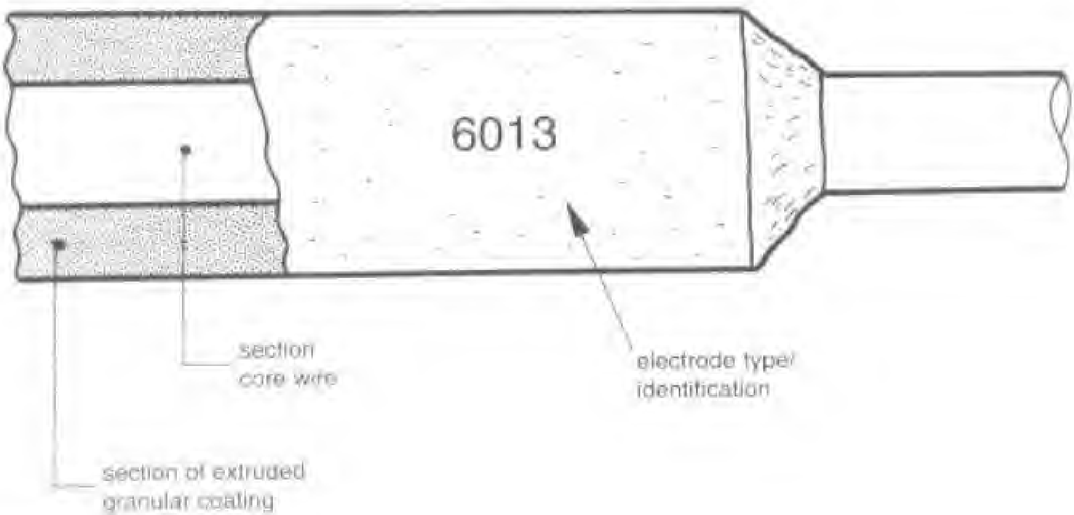
Manual metal arc welding electrodes are made in lengths varying from 200mm to 450mm and range in diameter from 1.5mm to 8.0mm.

The core wire is selected to match the chemical composition of the metal being welded as closely as possible. Some adjustment is made to allow for loss of alloying elements in the arc, though in some cases it may be easier to add alloying elements via the coating.

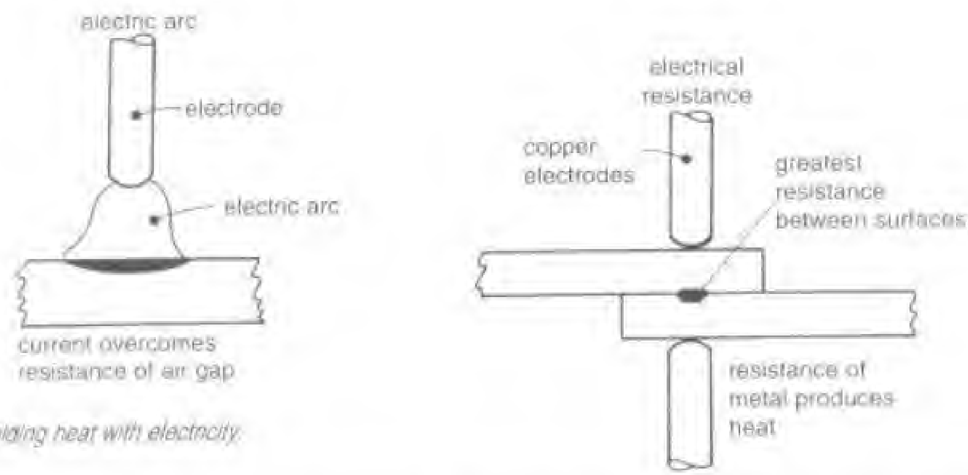
In surfacing applications, whether to resist abrasion or corrosion, the electrode will clearly be different to the parent metal. This is also the case when welding dissimilar metals, such as carbon steel to cast iron.

The core wire is coated with an extruded flux layer, which has the sandy texture of hard mortar. It is typically dyed, which often helps with electrode recognition.

Some electrodes have the abbreviated rod



Identifying electrodes.



Producing welding heat with electricity.

name inked on the coating and/or a series of figures which indicates its classification. In the UK 'E4631NiB54H5' is a particular category in BS EN499:1995, whilst '6013' is a very common American coding for general purpose, positional rods.

The Electric Arc

The two main ways of using electricity to produce heat for welding are from electrical resistance or from an arc.

The arc in all these processes is the visible evidence of electricity jumping a gap between the end of an electrode and the material being welded. More importantly great heat is produced as the current overcomes the electrical resistance of the gap.

The heat generated is at approximately 4,000°C but will vary between electrodes

depending on what gases are present. The amount of heat is controlled with a combination of current setting and electrode size. Increasing the current produces more heat but if the arc becomes erratic then a larger electrode is needed to accommodate the greater current.

Earthing

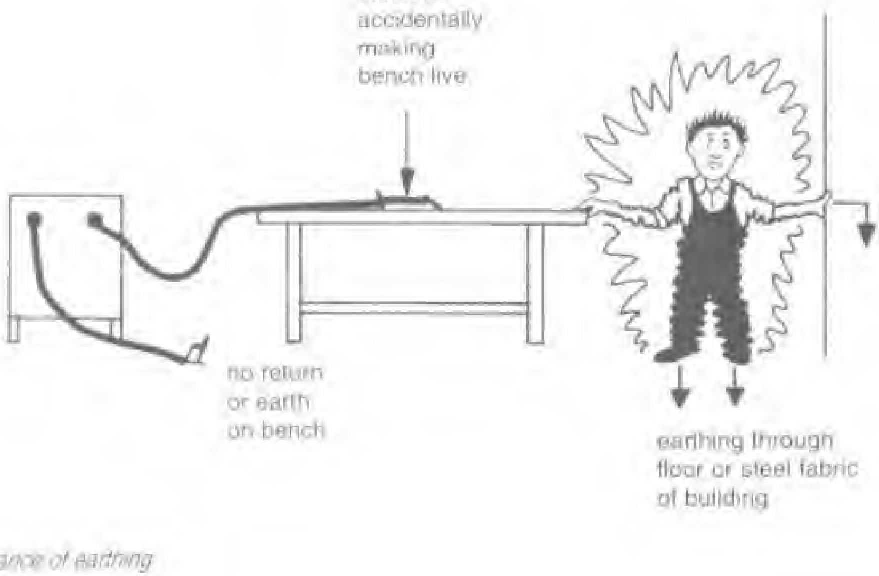
The safest working situation is one where both the primary or generating side of the circuit and the welding circuit – the work, or bench it is on – are earthed. All metal which may intentionally or otherwise carry an electrical current must be at earth potential. This ensures that if there is a breakdown in the welding circuitry, or if the return lead is ineffective, or if the steel fabric of a building becomes 'live' then the earth trip is activated, current ceases to flow and a potentially dangerous situation is made safe.

If there is no earth on the work and the return circuit fails then current may complete its circuit through the earth wire in portable electrical equipment like angle grinders, causing damage and perhaps a fire. Alternatively, other metallic items with which the bench is in contact or electrically connected to will become 'live'.

OBTAINING EQUIPMENT

The selection of an MMA welding set will be determined after considering the electrical characteristics required – its dependence on a mains electricity supply, the maximum current and voltage required, the cooling method and duty cycle. The welding equipment market is as competitive as any and there is a wide range of choice compared to O/A equipment.

The initial purchase is likely to be for a complete package comprising the welding set, both leads and a holder, with some



The importance of earthing

accessories thrown in, perhaps. The items can also be purchased individually. The same vendor will also supply electrodes, acting as an agent for one of the many large electrode manufacturing companies. Very small quantities can probably be obtained from DIY stores, but at a high unit cost.

MAINTAINING/REPLACING EQUIPMENT

Welding Plant

Transformers need practically no maintenance and rarely break down because there are no moving parts. Oil-cooled types will need the level checked roughly every two years, but could well go for twenty years without needing any topping up. Transformer oil should be used, of course, which unlike mineral oil is electrically non-conductive.

Rectifiers are not immersed in oil and the only maintenance necessary is to take the side/rear panels off and remove the dust build-up periodically by blowing through dry compressed air. Printed circuit boards (PCBs) can break down occasionally, but the reliability of rectifiers is now very good. The life expectancy of a rectifier, that is, the length of time that 'spares' can be expected to be readily obtainable is seven years. This is one of the factors influencing the choice between repair of or replacement of the set.

Generators need lubrication of moving parts and renewal of brushes as necessary, along with a supply of diesel.

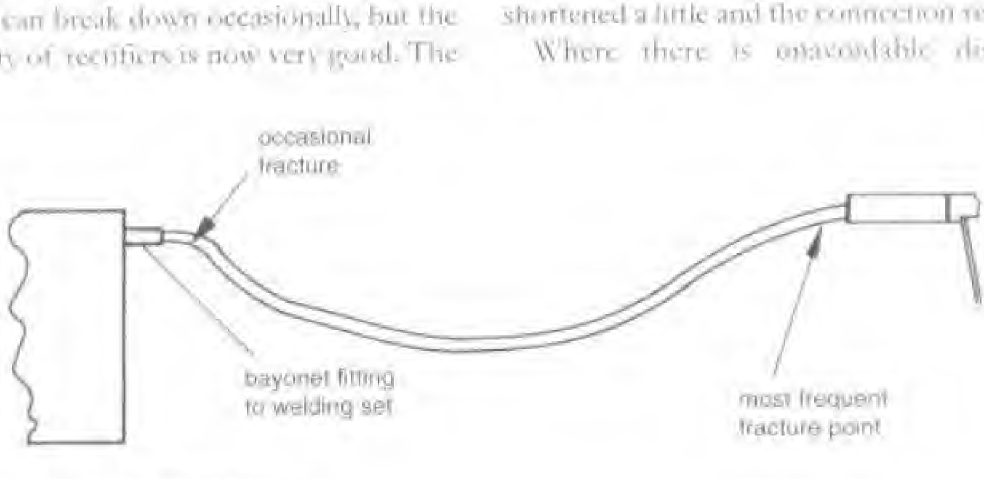
Welding Cables

Cables for welding are sized in terms of their current carrying capacity, and to avoid over heating they will need to match the maximum output of the welding set.

The protective rubber coating must be checked regularly in order to prevent electrocution or electrical damage to other equipment, and it must be ensured that spatter or hot metal does not burn through the insulation.

After prolonged use, flexing near to either the welding set connection, or particularly the electrode holder, causes the wire strands to fracture, reducing the effectiveness of the conductor, eventually the cable may even fracture right through. The cable needs to be shortened a little and the connection remade.

Where there is unavoidable distance



Fracture danger points in welding leads.

between the welding set and the work the cables can be lengthened, but this must be done with caution. Making a conductor twice as long also doubles the resistance, which in turn doubles the heating effect. If the cable is being used at more than half its capacity then it should not simply be made longer but also larger in cross-section. This will reduce the heating effect and loss of power at the arc. Use proprietary cable connectors for either lengthening or repair work, since DIY alternatives are likely to leave part of the conductor exposed.

Electrode Holders

Rough handling may chip the handle, exposing 'live' metal. The electrode jaw grip will become spattered and corroded and eventually worn to the point where it needs replacing; thus the only maintenance possible with holders is to use them with care.

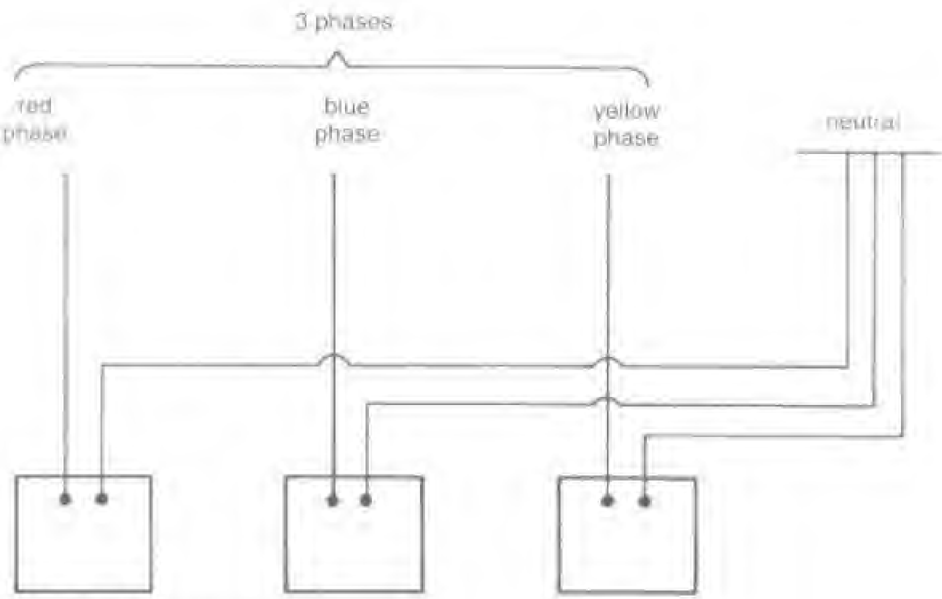
INSTALLATION AND ASSEMBLY

Electrical Supply – Primary Connections

If a portable 140A set is supplied fitted with a 13A plug and then placed in a dry, stable situation, it is ready for use. In industrial situations the fitting of an appropriate plug will be governed by company policy and must be done by a suitably qualified person.

The electrical supply to the welding set must be capable of handling the maximum demand that may be made of it, and this assessment is best made by an electrician. Overloading the supply will simply keep 'tripping' the trip switch.

Similarly, an electrician is best qualified to make arrangements for the installation of a number of welding sets, making appropriate terminal connections and balancing the load across the phases of a three phase supply.



Balancing the load across a three phase supply

Welding Circuit – Secondary Connections

Once the welding set is safely installed then the welding operator can make the following connections as necessary.

1. Electrode holder to welding lead. The bared end of the lead is invariably clamped in position with a number of Allen screws. Remove the holder sheath and slip over the lead. Expose the lead end, clamp in place and slide the holder sheath back over the assembly ensuring no bare metal is exposed.
2. Welding set to welding lead terminal. Bayonet fittings which are pushed onto the welding set terminals are fitted in the same manner as electrode holders. 'Lug' connectors are placed over a threaded terminal on the welder and held in place with a nut. The lead is secured to the lug by soldering (see Chapter 2).
3. Return lead connections. These will be made in the same manner as the welding lead connections but a device needs to be fitted at the 'work' end that enables it to be attached to and removed from the work quickly. Variations are quick-release G-clamps, standard G clamps, spring loaded crocodile jaws and magnets. Where all work can be done on a bench then a soldered lug fitting bolted semi-permanently to the bench is a cheaper alternative.
4. Establishing an earth. An effective earth should be attached to the work or bench in addition to the return lead. Often the most practical source of earth bonding is the steel frame of the building, but again if in doubt have an electrician sort it out.

MMA WELDING ACCESSORIES

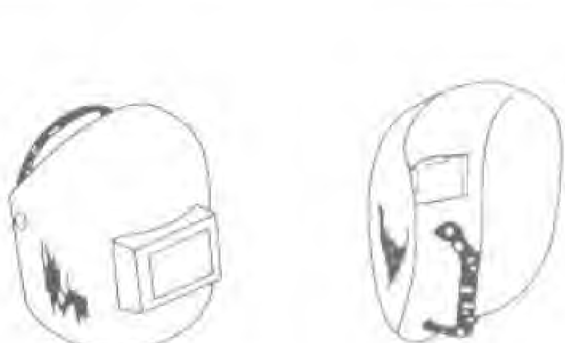
With a supply of electrodes the equipment is ready for use, but a number of accessories are either necessary or useful.

Welding Screens

Face screens are necessary to protect the face from exposure to harmful radiation emitted by the arc. They need to be light and robust, must cover the full face, and carry a filter glass through which the bright arc can be observed.

The initial choice is between a head screen and one which is hand held. The former leaves both hands free, which is essential in TIG welding, for example. When MMA welding, the free hand may be used to hold a piece of metal in place for tacking, or to hold a ladder or column for stability. Hand-held screens are less claustrophobic and less tiring and provide a receptacle for the electrode holder when it contains a 'live' electrode that is not being used.

All screens contain a filter glass which reduces the intense light of the arc so that it and the weld pool can be viewed comfortably. The glasses are categorized in BS 679 with higher numbers for darker ones to suit the increased light emitted at high amperages.



Head shields for arc welding

The filter glass is protected on the outside and possibly the inside with a clear glass or plastic which is much cheaper to replace than the filter glass itself when it becomes opaque from weld spatter or clouding.

Process	Current	Filter
manual metal arc	up to 100	8/EW 9/EW
	100–300	10/EW 11/EW
	over 300	12/EW 13/EW 14/EW
MIG	up to 200	10/EW 11/EW
	over 200	12/EW 13/EW 14/EW
TIG	up to 15	8/EW
	15–75	9/EW
	75–100	10/EW
	100–200	11/EW
	200–250	12/EW
	250–300	13/EW 14/EW

Two other types of filter are gaining in popularity despite their expense.

The first has a standard dark filter glass, but above it is a shallow field of view with the density of a gas welding filter, so it is just light enough to see through in daylight. The welding scene is viewed through the light area, with the head lowered, and when fully ready the head is raised and an arc struck, which is now viewed through the dark area.

The second type has a filter glass that is perfectly clear, but darkens the instant an arc is struck, without any discomfort or damage to the eyes. They are powered with a small battery and on some the depth of filter is adjustable.

To appreciate the advantages of these screens it must be realized that between placing a conventional screen in front of the eyes and striking an arc, there is a period of complete darkness during which time the electrode end can stray well away from the desired striking point!

Chipping Goggles

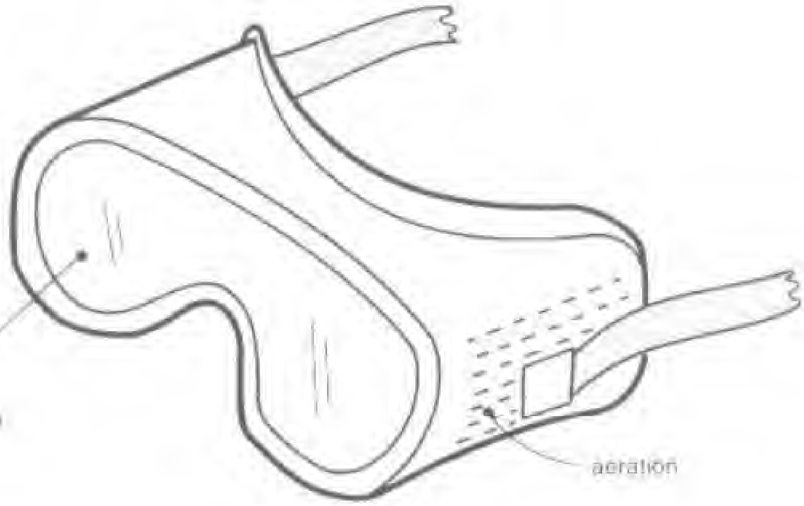
The electrode coating melts as it goes through the arc and solidifies on the completed weld as slag. Removal of this is necessary so that further weld beads can be deposited, whilst removal from completed welds permits inspection of the weld and prevents it corroding.

The operation is hazardous because chipped pieces of slag are angular and sharp, causing much discomfort and damage if they enter the eye. This is doubly so if the slag is removed immediately after welding because hot slag can adhere to the skin or eye surface and be difficult to remove.

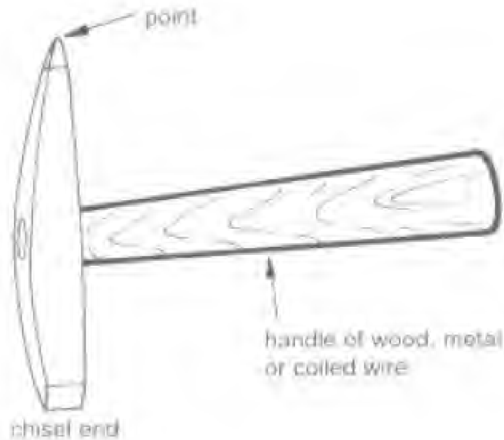
Chipping goggles or a similar clear protective screen will eliminate this source of injury.

Chipping Hammers

These hammers are made specifically for the purpose of weld slag removal and have a pointed end and a chisel end. The point is necessary at times to get into three-sided corners or into recesses, but it is possible to control the flying slag very skilfully by imparting



Chipping goggles



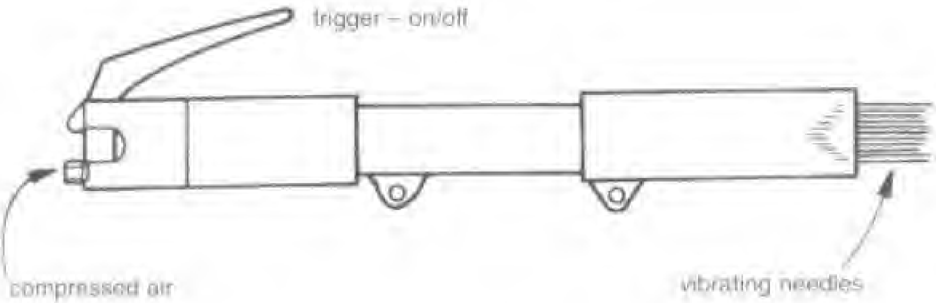
Chipping hammer

a glancing strike, away from the body, with the chisel end.

A crude alternative is to strike a blow on the joint with a ball-pane hammer. This can be quite effective but of course leaves a hammer indentation.

On a production basis 'needle' guns are used. These are pneumatic and contain a series of 3mm diameter hard rods whose ends vibrate up and down on the weld surface.

As a rule of thumb complete as much welding as possible, then remove all the slag. This makes the most effective use of time, and the cooled slag is easier and safer to remove.



Needle gun

Protective Clothing

The primary concern when welding is not protecting street clothes but protecting the body from the radiation and heat generated by the arc. Ultra-violet radiation burns any exposed skin in the same way as very intense sunlight. This exposure may not be direct. Light-coloured clothing or reflective surfaces like polished metal or white walls must also be avoided. The short-term effect can be deep, painful burning, which, like sunburn, may not be fully appreciated until it is too late! In the long term exposure to UV radiation can cause skin cancer.

An overall/boiler suit may be satisfactory for most work, but the additional protection of a leather apron is highly recommended. Leather gauntlets are essential; they should offer a good resistance to heat (one hand is very close to the arc) whilst also protecting the wrist and lower arm from radiation burn.

When welding on a vertical or overhead surface some form of head protection is useful, and the purchase of a leather skull cap may be justified.

Finally, steel toe-capped boots are essential, as they generally are in engineering. When working with pieces of metal large enough to damage the foot, sooner or later a piece will! Allow trouser legs to overlap the boots to prevent welding spatter entering the top of the boot: a welder is instantly recognizable by the number of holes in his socks! In extreme cases, such as when heavy arc or gas cutting, leather spats are available to protect the lower leg from spatter burning.

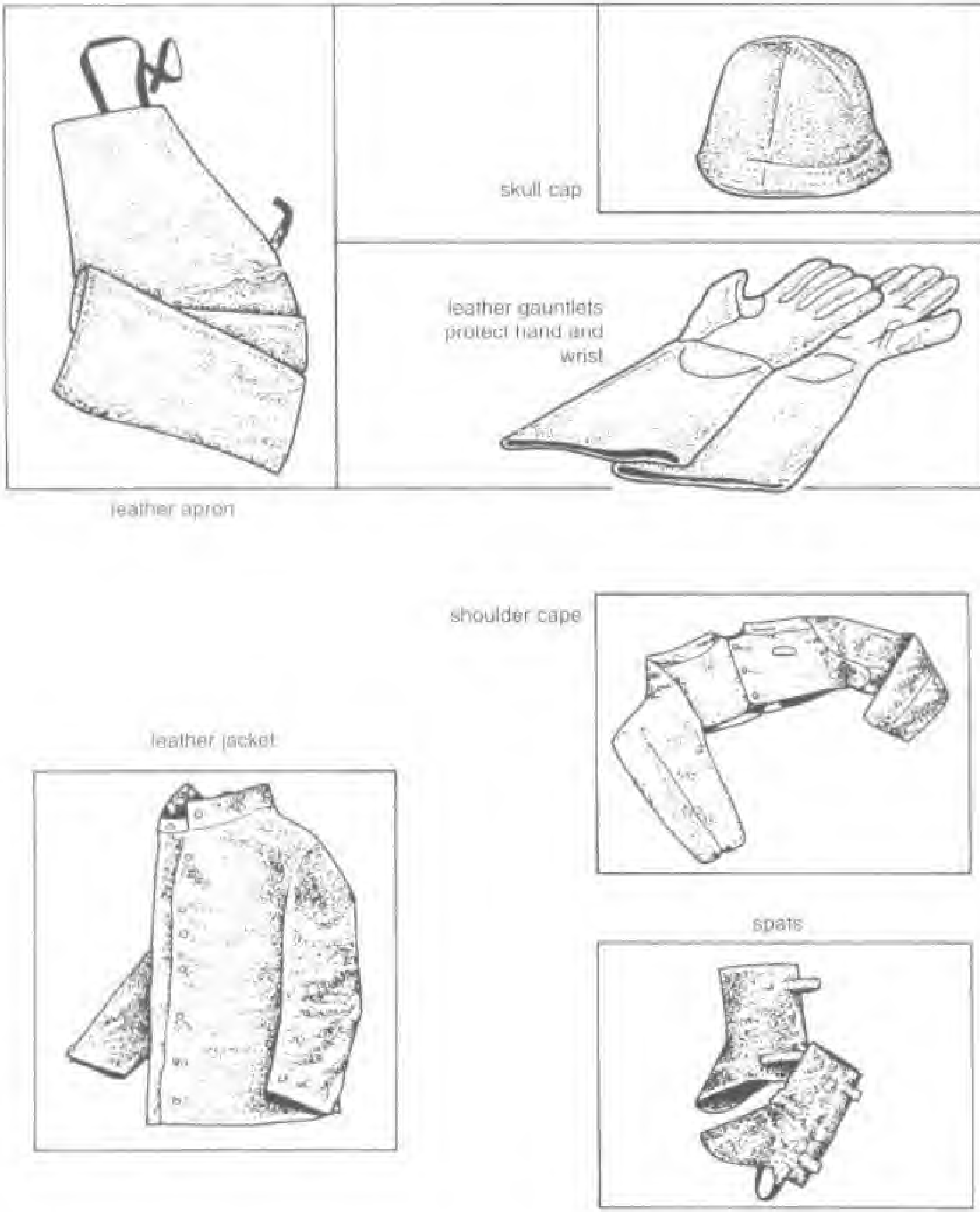
Other Accessories

The same accessories as those required for gas welding will be necessary when assembling metal by any process. MMA tasks tend to be heavier and may therefore require more robust clamps, jigs, hammers and so on.

USING ARC WELDING EQUIPMENT SAFELY

Once you have become familiar with arc welding equipment, it is important to understand the hazards that may affect the health or safety of the operator. The sources of these hazards may be broadly categorized as follows:

1. Electricity
2. Radiation
3. Fume
4. Heat
5. Slag



Protective clothing.

Electricity

Anyone dealing with electricity should exercise caution and this must include the welder, who has perhaps 200amps running through the centre of his hand!

Electrocution occurs in one of two ways: by (a) completing, or forming part of the circuit or (b) 'earthing' the circuit. The danger period is when the welding set is turned on and described as being 'live', but before the arc is struck. Once the welding arc is under way the electric current has established a path, hopefully through the intended circuit, and at this point it is most unlikely to seek an alternative path through the operator.

When the welding set is turned on and the circuit is open just before striking an arc, there is no current flowing. However, if the operator closes the circuit, for example by placing one hand on the bench/work and the other on an exposed part of the electrode holder, the current may attempt to find a path through him. Alternatively, touching the 'live' holder may provide a path to earth if the operator is working outside in wet conditions.

The currents used in welding are well above those needed to cause death but in fact are rarely fatal. The secondary effect of being thrown off scaffolding may, however, prove more disastrous.

Assuming that the welding equipment is properly installed, electric welding shocks can be avoided by working in dry conditions and ensuring that no bare conductor is exposed, that is, that all insulation is in good order.

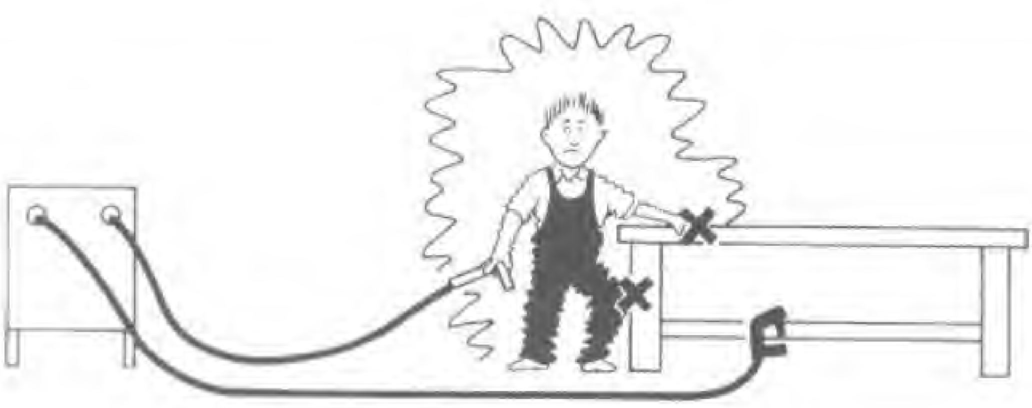
Radiation

Energy from the arc is radiated on three bands of wavelength:

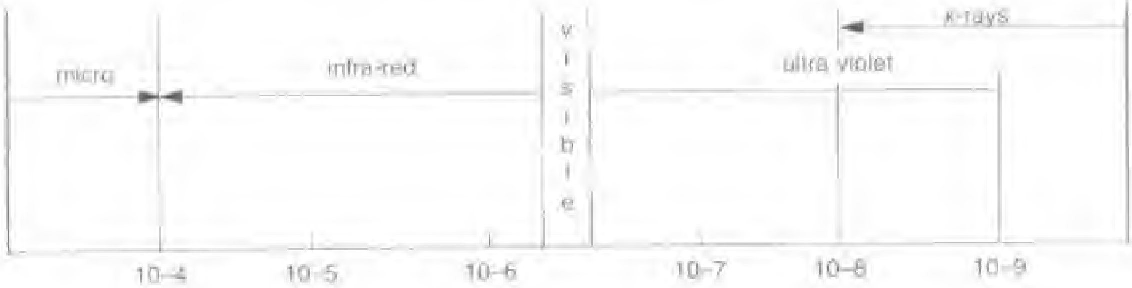
1. Infra-red (heat)
2. Visible light
3. Ultra-violet

Radiated Heat

Heat can transfer from one point to another by conduction, convection or radiation, and of these radiation is by far the most effective. However, leather gauntlets provide adequate protection against heat radiated from the arc.



Completing the circuit



The spectrum

Visible Light

The light emitted from the arc is so intense that it cannot be viewed without a filter. These are categorized in Britain in BS 679 as discussed under Protective Clothing in Chapter 3.

Ultra-Violet

Light on this wavelength is filtered out as it passes through any piece of glass. The welding filter glass is coloured primarily in order to reduce the visible light passing through it, but it does also filter out ultra-violet radiation as well.

'Arc-Eye'

If the arc is viewed with the naked eye then there are both short and longer term effects. Initially the iris contracts to compensate for the bright light to which it is momentarily exposed. The operator may see bright lights or stars, but the view is basically one of darkness, until normal vision is gradually restored over a period of 10 to 40 seconds.

Welding may now continue, without any discomfort, or further thought, until some time later the eyes feel extremely painful and as if they are filled with sand. This condition develops about 4–6 hours after the exposure which caused it, often out of working hours, and can be painful enough to wake the operator from his sleep.

The amount of pain suffered varies with:

1. The current being used
2. How closely the arc is observed (over 30m away is 'safe'!)
3. How long and how many times the eye is exposed to the arc
4. The angle at which light enters the eye – entry from the side seems to be worse

To prevent 'arc-eye' occurring, the welder must adopt safe working practices, that is, he should always ensure that his eyes are protected by the screen before striking an arc. Due to the very manual nature of the process it is quite easy to strike an arc accidentally!

Operatives working with or near to welding sets are particularly susceptible, because they are not in control of, or perhaps not prepared for, welding. All welding areas must have suitable and adequate screening, and are best painted in dark, non-reflective colours. Operators assisting the welder must also have a welding screen, or look away at 180 degrees to the arc. Viewing the arc through closed eyelids is both possible and asking for trouble!

It is customary for the welder to shout 'Eyes!' before striking an arc to allow others to take appropriate action.

Prevention is of course better than cure and since I have had the good fortune to avoid anything worse than mild itching of the eye for the last thirty years, it is difficult for me to recommend a cure with first-hand authority! Some relief will be obtained from keeping the eyes closed and by being in darkness. Further advice on relief varies from the application of tea bags to antiseptic or astringent lotions. If the pain is severe or lasts for more than 24 hours, medical help should be sought.

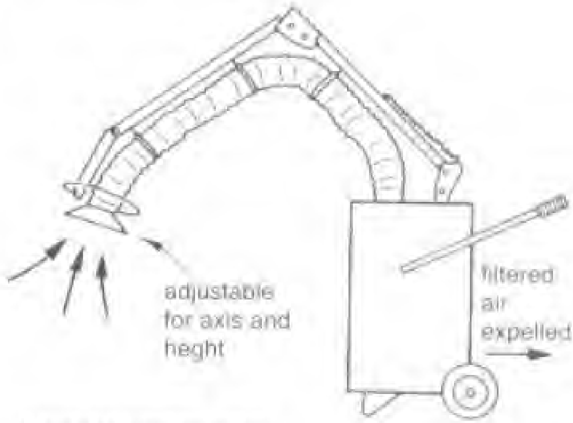
Fume

The effect of breathing in MMA welding fume is not as immediately obvious as getting a 'flash' but in the long term may actually do more damage. The early sign of breathing in too much fume is to feel drowsy and full-headed, rather like having a head cold. In the long term, inhalation of fume, with its high metal content, can only do irreparable harm to the lungs. The likelihood of breathing in fume is high when:

1. Working in a confined space
2. Many welders work in a small workshop
3. Welding metals with coatings of paint, plastic, zinc and so on
4. Using certain types of electrode, such as cellulosic coated ones

Fume health problems are reduced or avoided by:

1. Welding outdoors
2. Ensuring good ventilation by opening doors and windows to allow a draught of air through
3. Using 'air-stream' helmets (ones fed with a supply of air)
4. Using a fume extractor



A portable fume extractor.

The last method is best because it removes fume from the welding area and filters it, making the air safe before releasing it again. The extractor can be portable or part of a fixed installation. In either case it is essential to remove the fume at source and not after it has passed the operator's face, and also to maintain the filters so that clean air is discharged responsibly into the atmosphere.

Heat

Potential sources of burns are weld spatter, chipped slag getting lodged inside clothing, or slag burning through clothing and possibly setting it on fire.

Any piece of metal in a fabrication workshop might be hot, particularly where a number of welders work together. Despite exercising the greatest of care, burns are par for the course until eventually caution when

picking up metal is learned.

Burns are not only painful in themselves but the heat of the arc on the burns then makes further welding very uncomfortable.

Dealing with Burns

It is important to act very quickly to minimize the pain.

1. Make work area safe, but only to the extent of turning the flame off and putting the electrode holder down safely. Act quickly but do not cause any further accidents!
2. Run cold water over the burned area. This will bring almost total relief from the pain but equally importantly will prevent the burn spreading and becoming much worse than it need be.
3. Continue to keep the burned area under cold water for about 10 minutes, or until the burn can be removed from the water without warming up and becoming painful again.
4. Cover with a clean dressing and a gauntlet before continuing welding. Do not apply any creams of any sort.
5. Of course medical aid should be sought if the burn is extreme.

Heat Exhaustion

Welders can suffer from heat and dehydration in the same way as foundry workers. When engaged in heavy work on a hot day (or in a foundry!), or in a confined space and with a minimum dress requirement, care should be taken not to become too exhausted.

Slag

Much like burns, one moment of carelessness is rewarded with a long period of pain. Wear chipping goggles!!

PREPARING TO WELD

Preparing the Material

Chemically, MMA welding has a high tolerance for oil, paint, oxide and so on, because the fluxing action of the electrode coating is very effective. For high-quality welds to be produced, however, or where these contaminants prove to make the weld porous or brittle, the metal must be degreased and ground clean.

MMA welding is generally applied to thicker metals and this may demand suitable edge preparation in order to weld controllably through the full thickness.

Setting up for Welding

The following points will need to be checked before welding can commence.

1. Electrode type
2. Electrode diameter
3. Type of welding plant
4. Electrode polarity
5. Voltage setting on welder
6. Current setting on welder
7. The welding earth is in place
8. The return lead connection is made
9. The area is screened as necessary
10. The welding screen with suitable filter is available
11. The chipping hammer and wire brush are to hand
12. The components are set up and/or clamped together
13. The components are set up on bench

or can be approached comfortably

14. The welding set is turned on

Powered by	Welder type	Output current
petrol	► generator	► DC
petrol	► generator	► AC
mains electricity	► transformer	► AC
mains electricity	► rectifier	► DC
mains electricity	► transformer/ rectifier	► AC/DC
mains electricity	► inverter	► DC

Choosing a welding set to supply either AC or DC.

Electrode Type

A wide range of electrode manufacturers market a very similar range of electrodes, each under their own brand names. The choice becomes one of personal preference between electrodes with slight variation in deposition characteristics, but producing weld metal to the same specification.

Each type of electrode will satisfy a number of national and international standards, and also the standards of various authoritative organizations such as Lloyds Register of Shipping.

All carbon and manganese steel electrodes were classified under BS 639:1986 until 1995, when the European Standard EN 499 took its place.

The core wires of all low carbon steel electrodes are similar, and it is variation in coating that gives each type its user characteristics. The science of coatings is very complex and is influenced by cost, production requirements, arc striking capability, deposition characteristics, quality of weld metal and slag detachability. Three main types have evolved:

1. Rutile
2. Basic
3. Cellulosic

In terms of the mechanical properties of the weld metal, the significant differences between coating types is the low, medium and high hydrogen emission of basic, rutile, and cellulosic coated electrodes.

Rutile-coated electrodes. Recognized by the 'R' in their EN coding, these are general purpose electrodes for the welding of standard steels. They vary a little in tensile strength and ductility, and more heavily coated ones are restricted to welding in the flat (gravity fed) position.

EN499 E 46 3 1Ni B 5 4 H5

Hydrogen content
Welding position
Recovery and type of current
Type of flux covering
Chemical composition
Impact properties
Strength & electrode
Covered electrode
Standard No

A typical EN499 electrode classification.

Basic-coated electrodes. These are identified with a 'B' in their coding and are used where higher strength is required. Provided they are kept dry by only opening just before use or by baking and storing in an oven or heated quiver until required, they will not introduce hydrogen into the weld metal. Hydrogen absorbed at high temperatures can remain entrapped in the weld metal, producing gas

pockets known as porosity. Providing the cooling rate is slow enough the gas will diffuse out of the metal but the fast cooling rates of thick or cold steel, or the lack of ductility in high strength steels, may result in cracking as the cooling metal contracts around the gas pockets.

This problem is doubly aggravating because (a) cracks can develop hours or days after welding and (b) they are usually internal and cannot be seen; for example, in fillets they start at the root and grow towards the face of the weld.

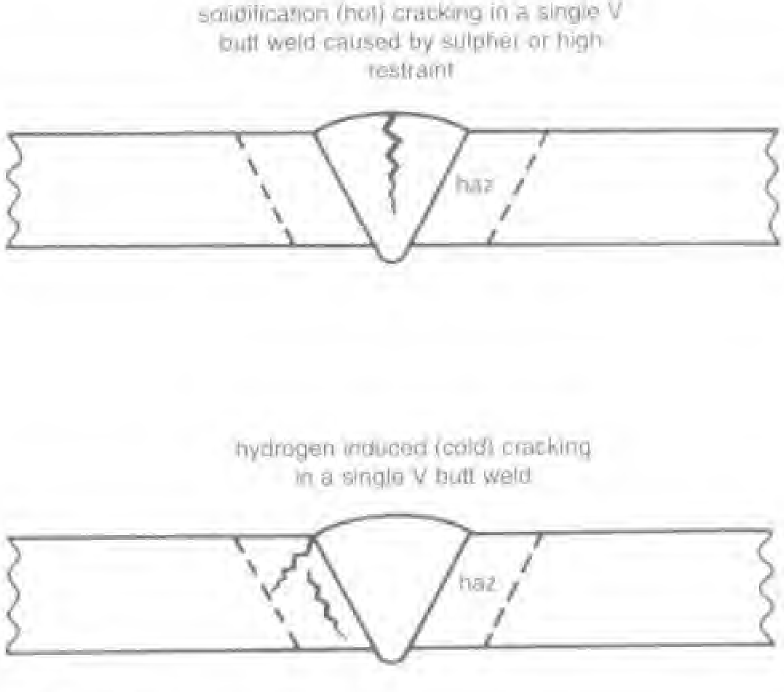
Cellulose-coated electrodes Hydrogen is detrimental to high-strength welds but it also increases the power and penetrating characteristics of the arc. Cellulosic coatings are high in organic material and hence high in hydrogen. They are used for deep penetration, and for welding vertically downwards. Weld beads are rough with high spatter.

Electrode Diameter

The selection of electrode diameter is a matter of personal discretion determined mainly by metal thickness unless it is prescribed in a welding procedure. Generally, the largest electrode possible should be used provided the weld deposited is not oversize.

If the electrode is too large then the weld pool will either blow right through the joint or simply be uncontrollable. It will be underfilled/undercut and look rough.

If the electrode is too small then quality welding is possible but requires much more skill. The small electrode running on a low current does not supply enough volume of heat to the metal to make fusion and flow of the weld metal easy, and hence the weld is



Sub-surface weld metal cracking.

prone to slag traps and lack of fusion. The volume of weld metal deposited by the small electrode is low, so building up a weld joint with sufficient cross-sectional area requires many more passes than would be necessary with a large electrode. This increases the amount of welding needed and lengthens the time it takes, which in turn increases the risk of weld faults.

Type of Welding Plant

Most MMA welding is done with an AC transformer because these are relatively inexpensive, efficient and require little maintenance. A DC welding set will be used where the electrode demands it, or perhaps for site welding, in which case the electrode polarity must be determined.

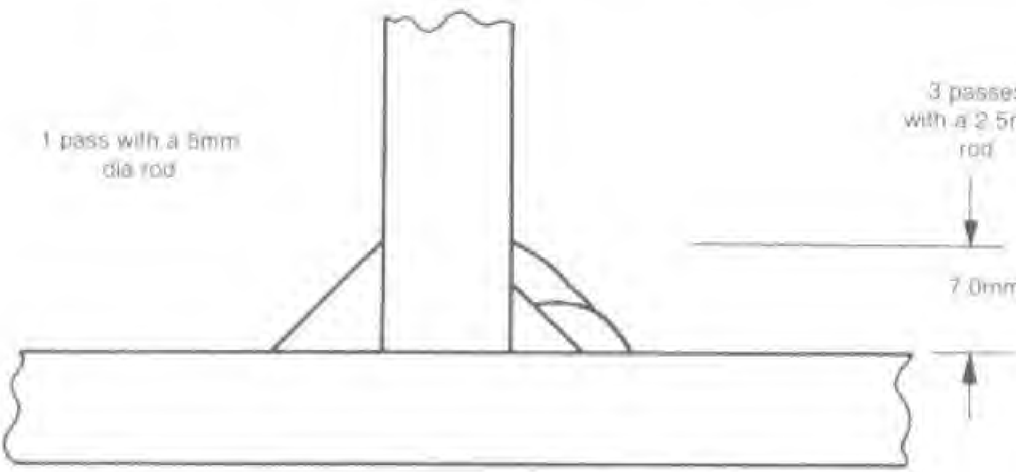
Electrode Polarity

In a DC arc more heat is liberated at the positive pole than the negative one. If the electrode is made positive it melts away in half the time it takes when the same size electrode is made negative. This offers a means of heat control in addition to electrode size, type of coating, current and voltage settings. When the electrode is required to melt with ease, as it is in MMA and MIG welding, it is made positive, but in the TIG process, where the electrode should not melt, it is made negative.

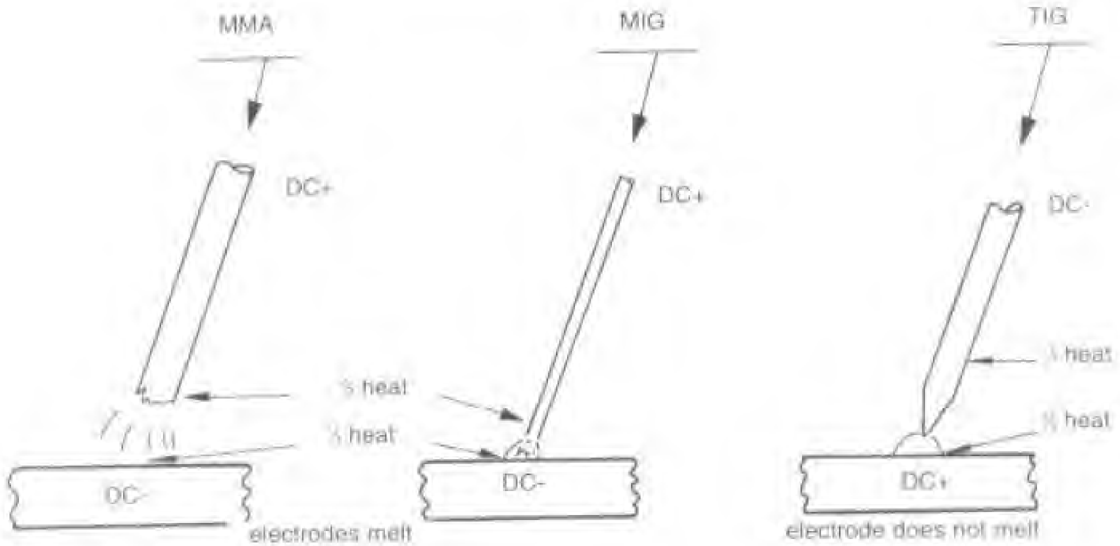
Penetration can be reduced to advantage in MMA welding when welding thin sheet, and for hard surfacing where minimum dilution of the weld metal helps it retain its hardness.

Voltage Setting

On welding sets offering a choice the voltage is selected by placing the return lead on the required terminal. If the set is now turned on, a voltage reading can be obtained across the output terminals. This is known as the 'open circuit voltage' (ocv), that is, the voltage that exists before the circuit is closed and current begins to flow. It is also known as the 'striking voltage', that is, the voltage necessary to get current to flow between the



Using different rod sizes to produce a fixed weld size.



The heat distribution in a DC arc.

electrode end and the work.

There must be a difference in potential of at least 45V in order to strike an arc. Higher voltages make arc striking easier, but are also more dangerous: the chance of the current flowing through the operator is also greater!

When manufacturers recommend an electrode current setting it is assumed that the welding lead is on 80V connection. Changing the open circuit voltage will alter the arc voltage too and also the current flowing through the circuit.

The recommended striking voltage will be found on the electrode packet, or can be determined from the EN499 classification. In keeping with continental safety requirements, most electrodes today will strike on 50V but there are still those that require a minimum of 70V, 80V, or 100V ocv.

If arc voltages were as high as the ocv the arc would be very violent and unstable, but manual arc machines are designed to allow for these conflicting needs. When an arc is struck, and the circuit closed or completed, current rises to the setting on the machine whilst the voltage falls correspondingly, typically down to about 22/24V.

The precise arc voltage will be influenced by:

1. The ocv, with low ocvs resulting in low arc voltages.
2. The electrode coating type. Different types and quantities of gas liberated from the coating as it melts will vary the electrical resistance, with increase in resistance producing a larger difference in potential across the gap.
3. The length of the arc, with longer arcs producing higher arc voltages. Again the increase in electrical resistance will cause a higher potential difference. If the arc voltage is caused to vary by changing the arc length then there is a corresponding change in cur-

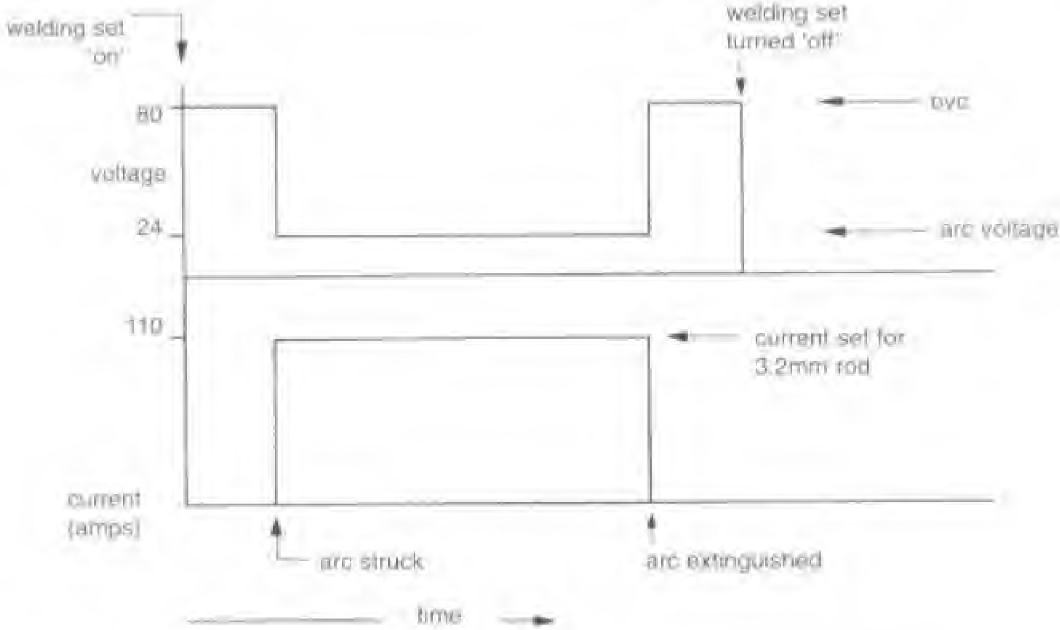
rent – shortening the arc will reduce the voltage and increase the current flowing across it.

An interesting exercise is to place a voltmeter and an ammeter in the circuit and observe the readings fluctuate as a colleague welds. The goal is to keep the arc length (and meter readings) steady.

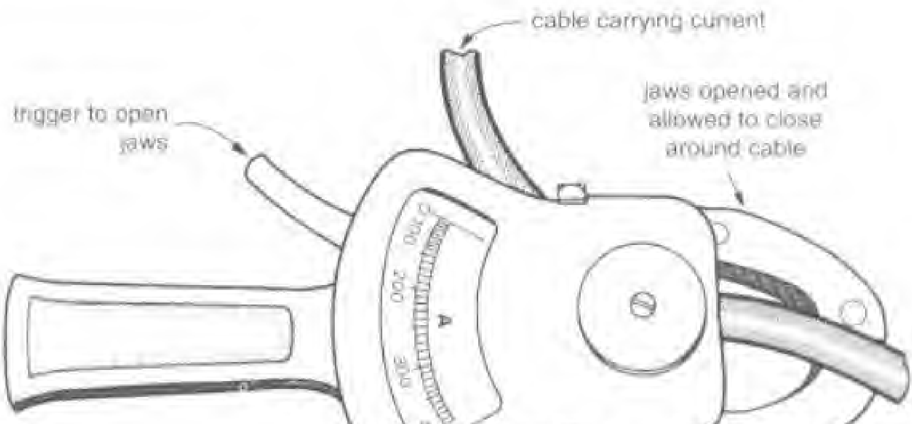
Current Setting

Transformers use either a tapped choke or a moving core/coil to enable different current outputs to be selected.

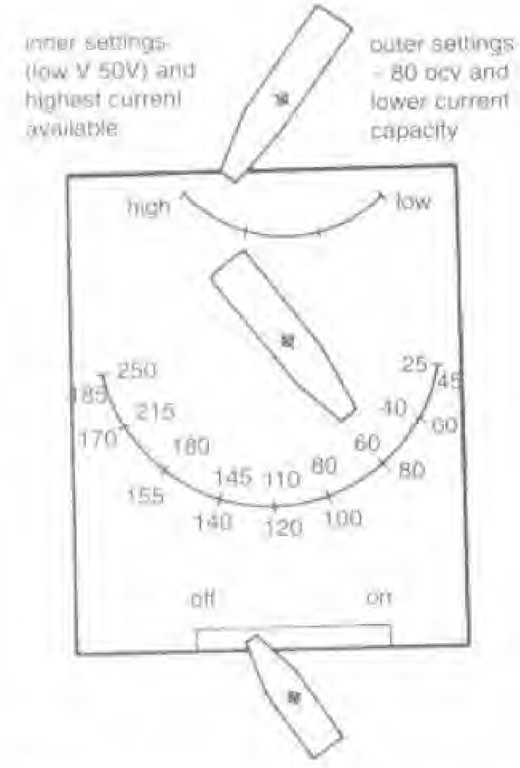
The first type provides a range of fixed tapped settings, obtained by moving switches or changing plug/socket connections, or a



The relationship between welding current and voltage.



A tong test ammeter.



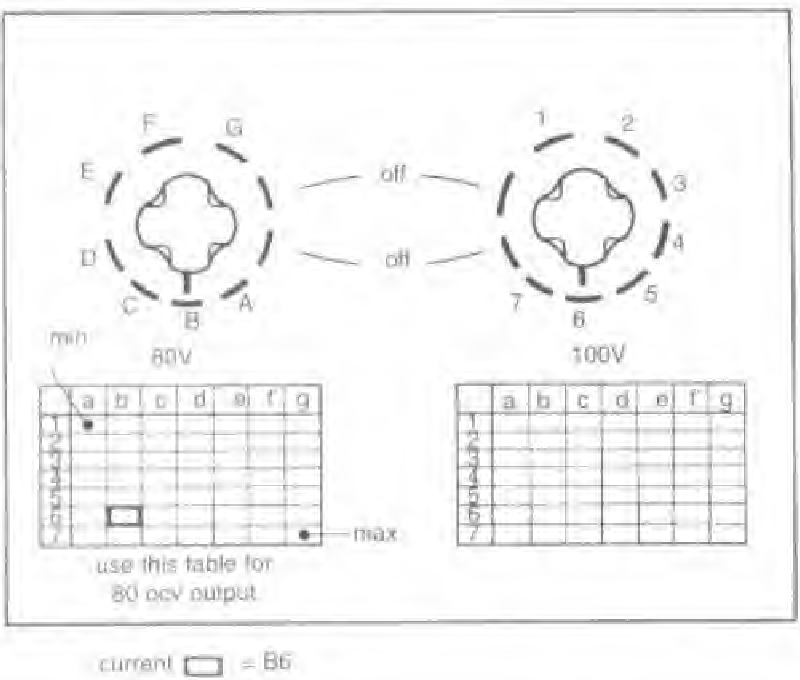
Transformer current control

combination of the two.

The second type is infinitely variable across the range and adjusted by means of a hand wheel, which regulates the position of a core or coil winding inside the welding set. This type offers much closer control of welding current, but the stepped type is usually quite adequate and can be adjusted more quickly.

There are often two ranges of current displayed on the welding set, one for each ocv option. The display is either in the form of a table, or in 'arcs' as in the diagram on the left. Care must be taken to read the correct display because a particular setting on, say, 50 ocv will supply a lower current if the ocv connection is changed to 80V.

The amount of current needed to melt the electrode successfully will vary with many factors and hence the current recommended for a given electrode size can only be approximate. If a manufacturer suggests that a



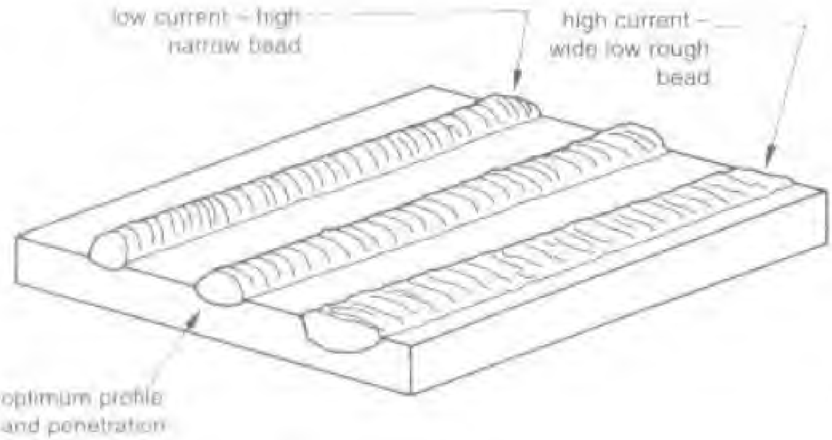
Transformer current control

electrode dia mm	current setting min	typical	max
2.0	50	60	75
2.5	70	85	100
3.2	90	110	135
4.0	140	160	185
5.0	175	200	245

Current required for various rod sizes.

4.0mm rod requires between 130 and 180 amps this is because it will work quite well throughout this range, and at times it will be necessary to use settings at each extreme. Unless the welding set is calibrated as part of a quality system, it is most unlikely to deliver precisely the current that is set, and it will vary a little with arc length in any case.

The current setting may be prescribed in a 'welding procedure' – a documented and proven way of welding that must be adhered to. Most welding, however, relies on the skill of the welder, and current selection is likely to be made on the basis of observation of the arc and successful welding in action, regardless of what current is indicated on the welding set.



Effect of current settings on weld beads.

MMA beads made with low, correct and high current.

MAKING A WELD BEAD

Striking an Arc

The arc is initiated by bringing the electrode end into contact with the parent metal so that current starts to flow through the circuit. The electrode is then raised above the plate surface about 3–4mm and current flows across the gap creating an electric arc with intense heat and light.

The easiest way of striking an arc, with consistent success, is to draw the electrode end through an arc, scraping the plate surface at the lowest point and rising finally to produce the arc length.

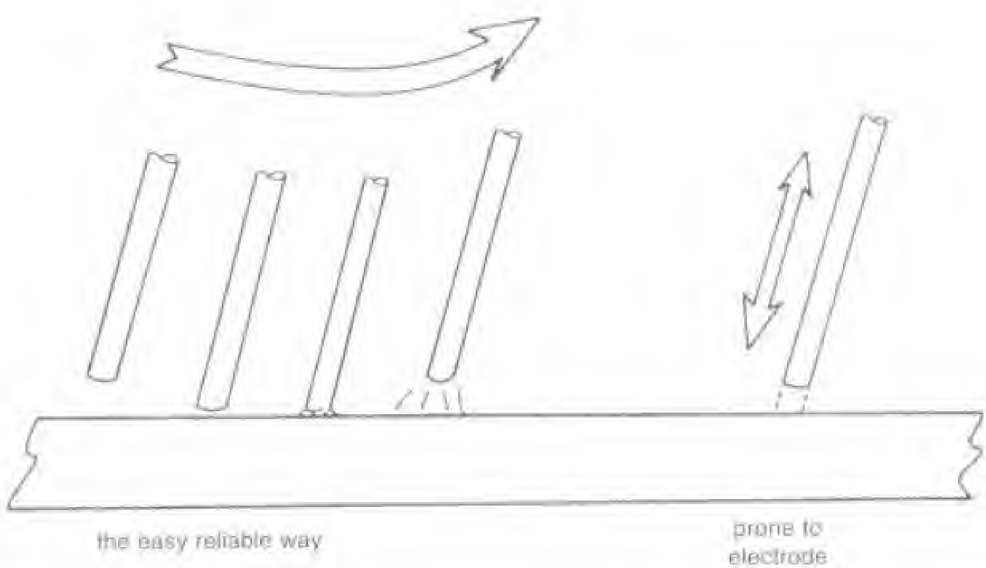
The alternative is to tap the electrode end directly onto the surface and lift it up. Whilst this method can be successful and accurate, it is very susceptible to sticking, which in the first method is prevented by the movement along the surface.

If the electrode does stick, the holder should immediately be firmly moved from side to side to release it, but beware of the flash that will occur at this moment. Failure to respond quickly results in the electrode resistance heating, which causes it to bend rather than break free. If it fails to release then the situation is made safe by turning the welder off, releasing the holder from the rod and then removing the electrode.

The sequence when striking an arc is:

1. Place the electrode end about 10mm above the starting point.
2. Keeping the electrode steady, place the screen in front of the face.
3. Strike the arc, and in the light now available relocate the starting point.

Difficulty will be experienced at first in striking an arc at a precise point. This skill must be developed because weld beads need to be



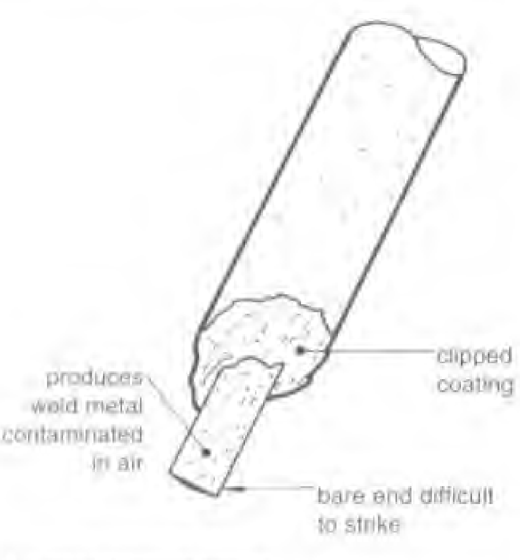
Striking an arc

started accurately at the start of the joint or at the end of a weld bead which needs to be continued. The difficulty arises at stage 2, above, where the one hand must remain quite still whilst the screen is being moved into position.

Common Difficulties in Striking an Arc

If there is no sign of life or sparking at the electrode tip then the following are possible causes. The first three are encountered most frequently:

1. The welder is not turned on, either at the isolator or on the welder itself.
2. There is no supply to the welder because the earth trip has been activated.
3. The return lead connection with the work has not been made well enough or has been forgotten.
4. A welding or return lead termination has broken down.
5. The welding lead has fractured near the electrode holder (beneath the insulation).



A chipped electrode coating.

6. The wrong end of the electrode has been inserted in the holder.

If there is evidence that power is available at the electrode but it is difficult to get it started then perhaps the:

1. Current setting is too low for the electrode in use
2. Electrode requires a higher ocv
3. Electrode requires a DC welding supply
4. Electrode needs changing from DC negative to DC positive

These factors can be confirmed by reference to the electrode packet. Alternatively the:

5. Coating may be chipped off the electrode end. Metal to metal contact must be made to complete the circuit but the coating is essential for easy arc initiation
6. Return lead connection is not effective enough
7. Electrode coating is damp; hydrogen increases the electrical resistance of the gap
8. Surface of the plate is heavily oxidized or painted, impeding the flow of current.

Starting a Bead

Practice in depositing a smooth regular weld bead on the surface of a plate is essential before considering trying to join two pieces together.

The action is one of slowly moving the electrode across the plate, whilst also feeding it towards the plate as it is consumed. This motion will be jerky at first but if the electrode is held at an angle of 60 degrees then it is simply a matter of lowering the hand perpendicularly to the plate, effecting

smoothness and also the correct speed of travel. This is because holding the electrode at 60 degrees directs the arc back into the weld crater, forcing the molten metal and slag towards the rear edge, whilst also allowing the arc to melt well into the plate surface, giving good penetration.

The arc will have a fine crackling sound like that of cotton being torn, or frying bacon. Its length is adjusted to equal the core wire diameter.

Welding is best done across the body rather than to or from it. In this way the arc length, electrode angle, weld build-up and joint line can all be observed with ease.

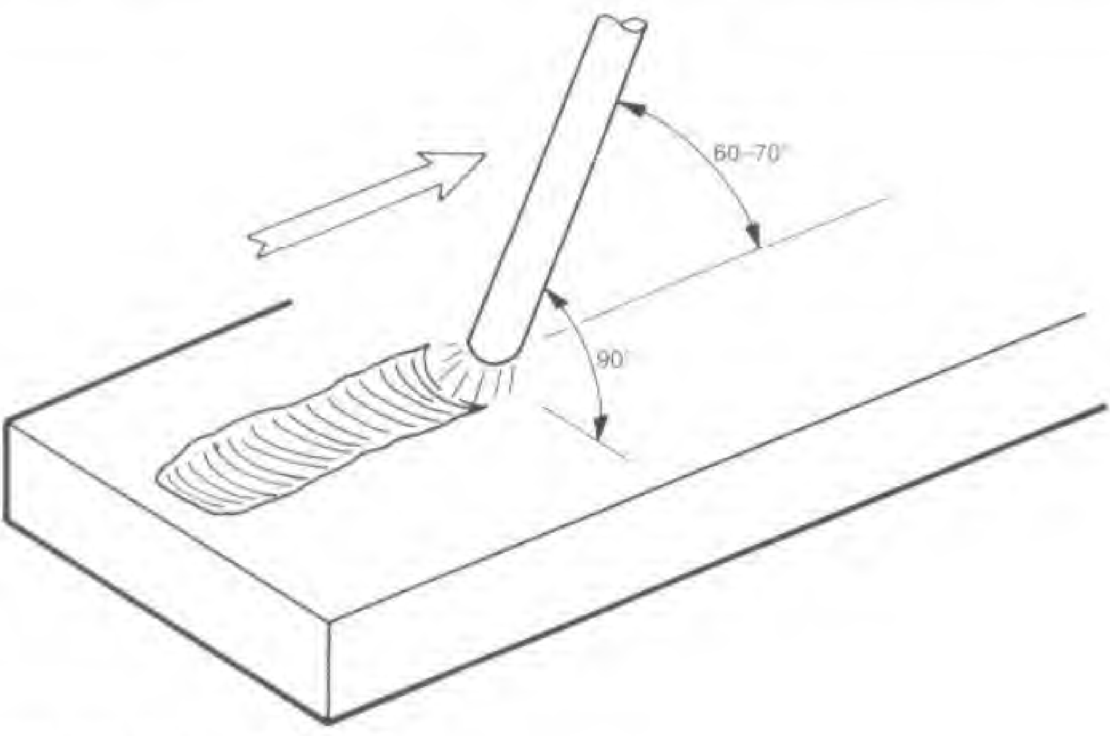
The electrode is melted away until about 25mm remains. After this the electrode coating will have worn off and heat damage to the holder is likely.

Continuing a Bead

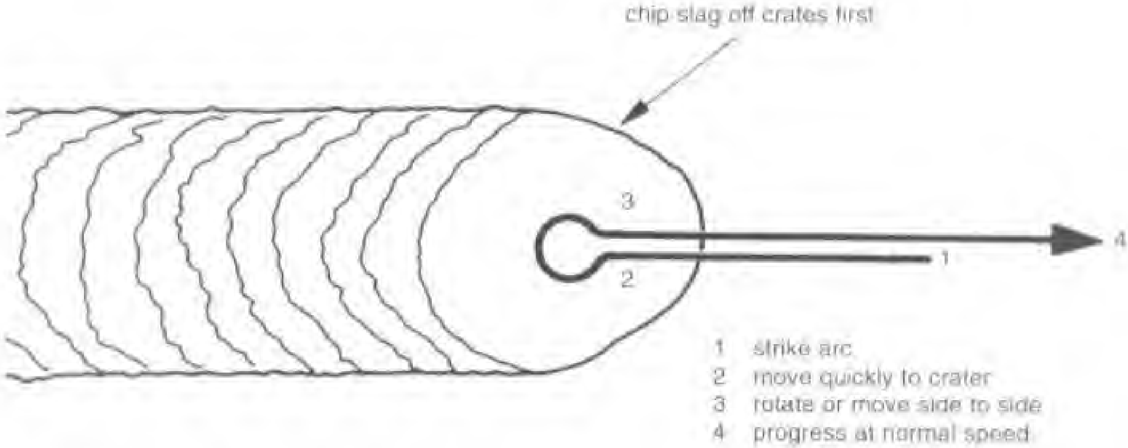
Weld beads should be made in one continuous operation if possible. The most likely reason for stopping a weld is that the electrode has expired; if this happens, discard the stub safely and insert a new electrode. Then recommence as follows.

1. Remove the slag from the crater and last 10mm of weld and clean with a wire brush.
2. Strike the arc ahead of the crater and move back into it. Move the electrode from side to side a little or round in a small circle (to encourage it to spread), then progress at normal speed out of the crater and along the joint.

With practice this join in the weld bead will be undetectable once the whole weld has



Running a bead on plate – electrode angles



Restarting a weld bead

been wire brushed. Despite this, faults exposed by examination of an X-ray invariably have a regular frequency, occurring about every 180mm; that is, they tend to be at the stop/starts.

Finishing Off the Bead

If the arc is simply extinguished at the end of the joint then it leaves a hollow crater which weakens the weld and which may crack as it shrinks on cooling. To fill in the crater:

1. Weld up to the point where the leading edge of the pool is at the end of the joint.
2. Pause for about 2 seconds to fill in.
3. Weld back in the opposite direction for about 5mm without changing the angle of the rod.
4. Withdraw the electrode promptly in the new direction.

WELD PADDING

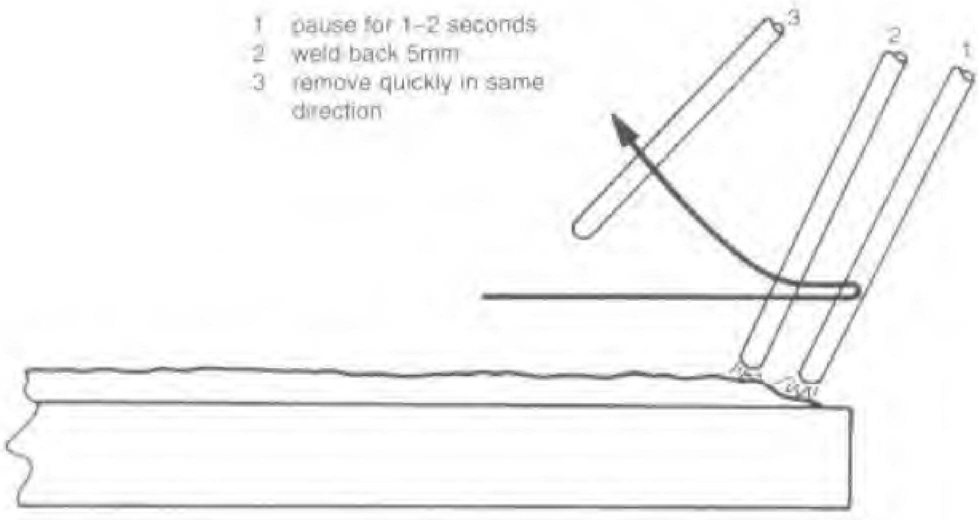
Practice in making weld pads is a very useful intermediate exercise between running straight weld beads and joining two pieces of metal together. It provides practice in 'aiming' the electrode at a joint line but the technique also has a number of practical applications.

A first weld bead is made along the surface of a fairly substantial plate, with minimum dimensions of 150 × 100 × 10mm, but the bigger the better. The bead should be continuous, extend over the full length, and on completion be deslagged and wire brushed.

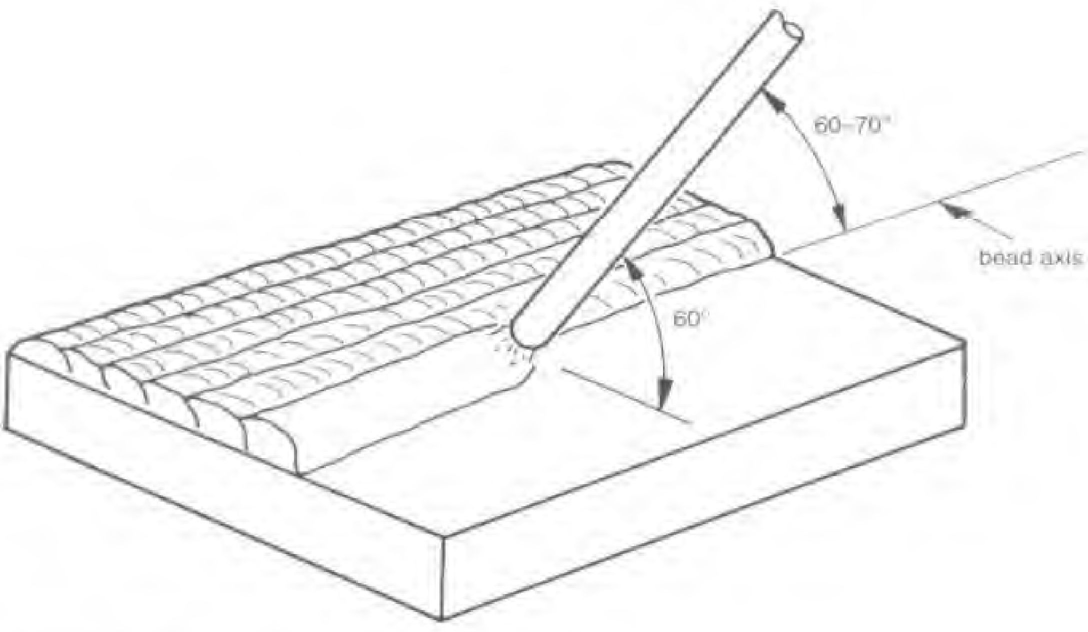
The second bead is not placed randomly on the plate but directed at the toe of the previous one, that is, the edge of the weld. The slope of the electrode is still 60 degrees but the tilt (the transverse angle) is now also 60 degrees, rather than the 90 degrees used for the first bead.

The effect of welding in this manner is that half the new bead covers the first one, whilst the remainder laps over new plate. After a number of passes have been made in this way, deslagging between each, the plate thickness will have increased by about 3mm.

It will be noticed that the bead profile is affected by the temperature of the plate at



Finishing a weld bead



Electrode angles for weld padding

Weld padding on a steel surface.

the commencement of each bead. As the plate warms up the beads will become progressively wider and flatter as a result of welding intensively in one area. The aim is for the surface of the weld pad of overlapping weld beads to be as flat as possible, so that machining the surface would require minimal metal removal to obtain a fault free, raised surface.

Practical Applications of Padding

This technique is useful for reclaiming worn surfaces, either with standard electrodes or with purpose-made hard-surfacing electrodes for improved wear resistance. If the wear has been caused by corrosion then corrosion-resistant alloy electrodes can be deposited to extend the working life.

In either case a suitable weld surface might be used to extend the anticipated life of a new component, often with the strength being supplied by the base metal and the wear/corrosion resistance being supplied by the surfacing layer.

MAKING WELDED JOINTS

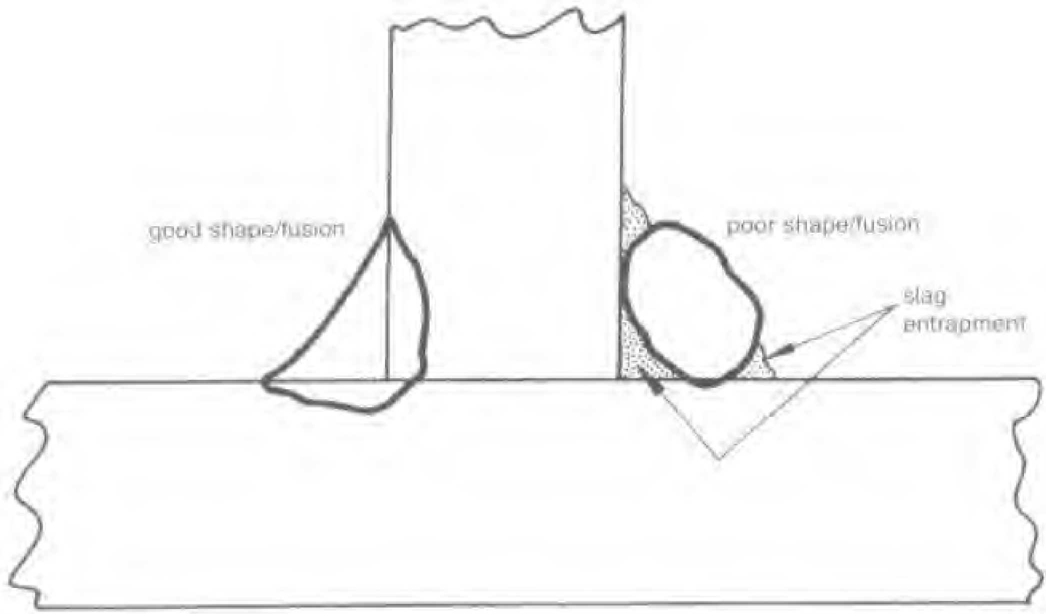
Most joints encountered in MMA welding are fillet joints, where the weld is placed in a 90-degree corner, without any gap. Butt joints are less common and more difficult to do well.

An edge meeting a surface presents difficulty in gas welding but MMA is much less sensitive to this sort of variation. Dissimilar thicknesses are not a problem either, provided that the thinner piece, or the one needing least heat, is not melted uncontrollably. For all welded assemblies the items need to be arranged in position, probably held with clamps, and tacked.

Tacking

The size and number of tacks needed are learned with experience. Each should be at least 6mm long and they should get longer but less frequent as the metal gets thicker.

It is important that the electrode progresses along the plate during the short period of



Good and poor tacking.

arcing so that the tack can blend in rather than build up in a 'blob' under the electrode end. It helps further if the electrode is one size smaller than that to be used on the job and the current is set 20 per cent too high. This causes it to strike very easily, fuse well and, again, blend in.

All tacks should be welded through and fused in as the weld progresses. Deslag and wire brush tacks first, and if the profile appears so pronounced that it will cause lack of fusion or a slag trap, then blend its shape with an angle grinder or a bull-nosed chisel.

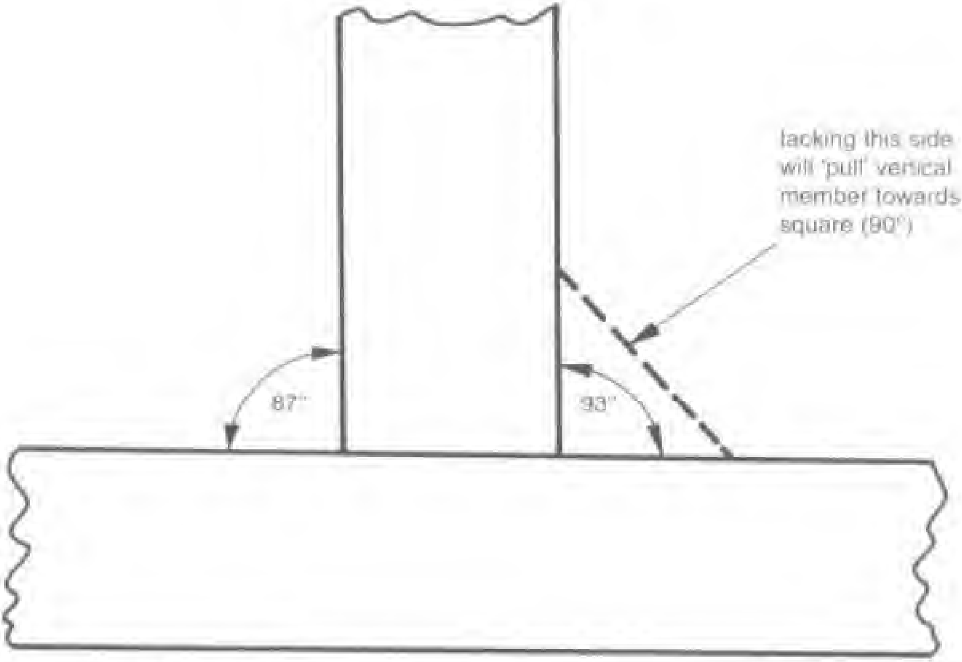
As the first tack contracts it will pull the plate into a new position. The position of the second tack can either compound this effect, or be used to balance it. Tacking on the opposite side of the joint should pull the plate back again. The contraction of tacks need not always be a nuisance because they can be used to pull components into shape when placed or sequenced with care. Occasionally tacks crack because they cannot accommodate the shrinkage that takes place during cooling. This is most likely where the cooling rate is very fast or where the joint is under high restraint. In this case use electrodes with a higher strength/ductility.

T Fillet Joints

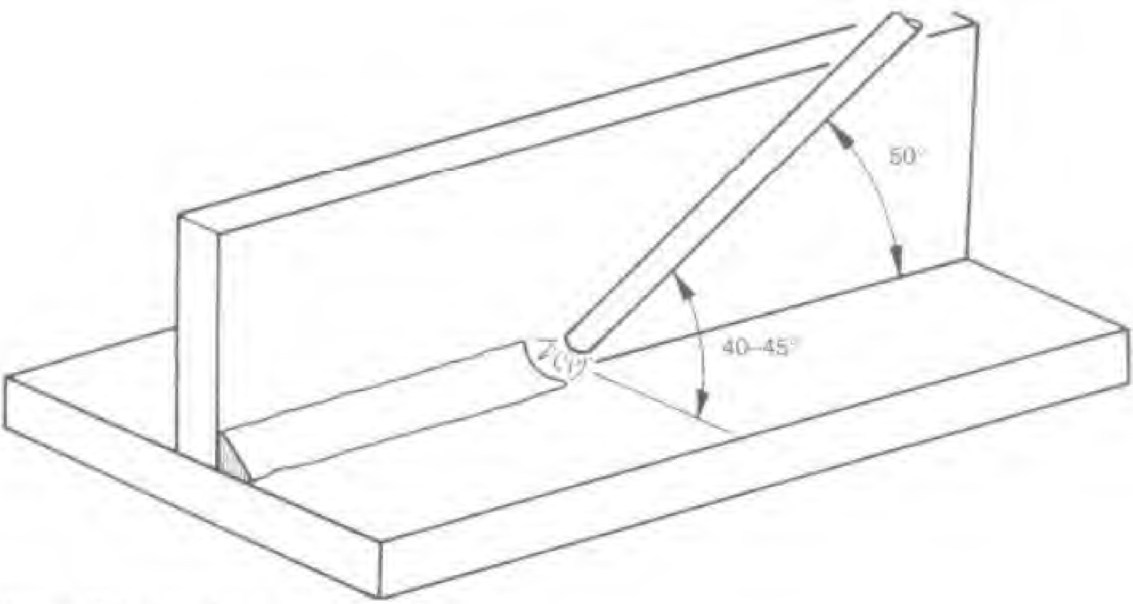
The plates are placed in position and held with a weight, corner clamp, magnet or clamps onto a piece of 'box-section', and tacked.

The first pass, known as the root run, is placed directly in the corner with a tilt angle of 45 degrees and an electrode slope of 50 degrees. Reducing the slope angle to 50 degrees helps to prevent the liquid slag build up on the weld surface from running down in front of the arc, which then gets in the way and causes slag traps.

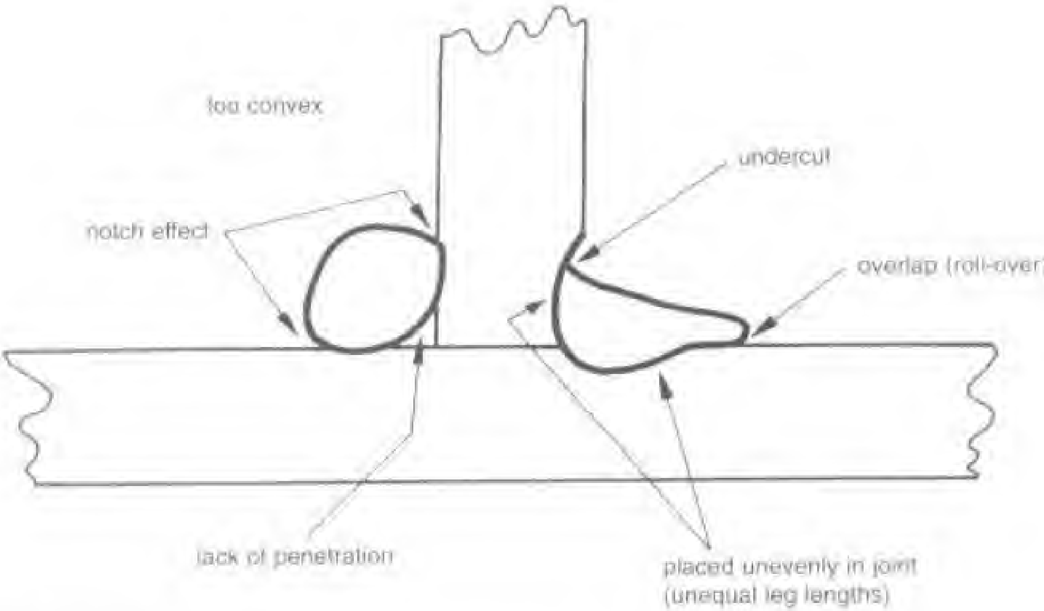
The weld should nominally have a mitre



Controlling movement when tacking.



Making a fillet joint root run.



Poor fillet weld profiles

profile. Concave welds look good but are weak through the centre whilst convex welds have an undesirable 'notch effect' at the toes.

Size and Quantity of Welding

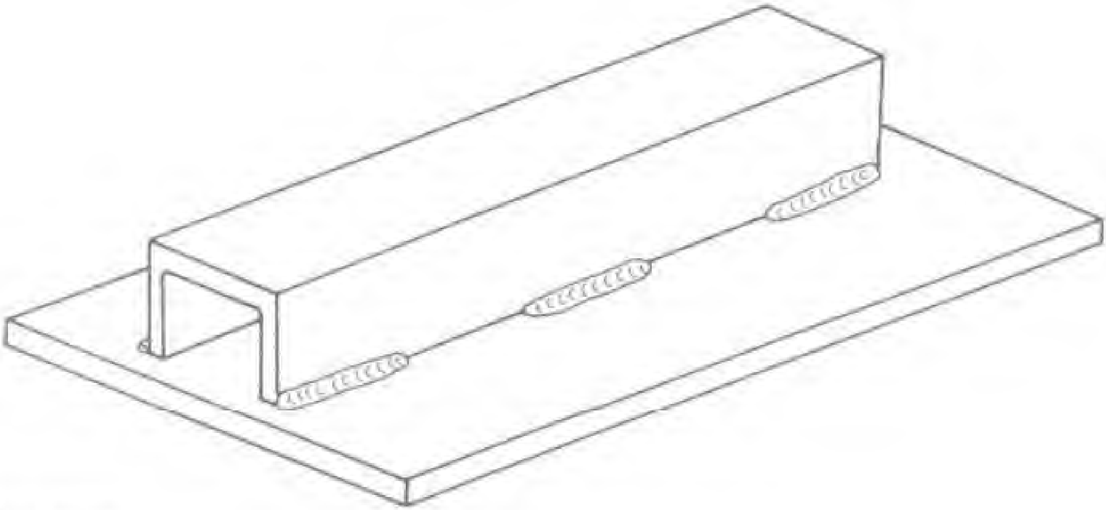
The size of the weld required to keep a T fillet joint in place varies greatly, and will depend on the type of load it will be under. If the total load is vertically down through the web then the tacks would probably keep it in place. If, however, the loading is at right angles to the web then the weld may need to be as strong as the parent metal. To achieve this, the leg length needs to be equal to the plate thickness if welded from one side, or half the plate thickness if welded from both sides.

The leg length can be obtained by welding in a number of passes with a small electrode; or in just one pass if it is possible with a large electrode.

The amount of welding necessary also varies greatly. Both the size and amount will be directed in a weld procedure, standard company practice or simply based on experience. Possible variations are:

1. Continuous welding, single pass, one side only
2. Continuous welding, single pass, both sides
3. Continuous welding, multi-run on one or both sides
4. Intermittent or stitch welding on one side only
5. Stitch welding on both sides directly opposite each other
6. Stitch welding alternately on each side

When welding multi-run fillets the electrode slope for further runs will revert to 60 degrees because the joint profile is now more



Stitch welding

open, and slag control is less problematic. On the second pass aim at the lower toe of the root run with the intention of covering about two-thirds of it; the tilt angle should be 65 degrees. On the third pass aim at the centre of the V formed by the plate surface, the exposed part of the root run and the top half of the second run; the tilt angle should be 30–40 degrees. If another layer is needed then repeat as for the second pass until the final pass at the top which is done as for the third pass.

Note that in all multi-run welds of this type weld metal is placed at the lower side of the joint first to provide a 'step' on which to place further weld metal. Note also that it is always necessary to deslag beads between passes.

Lap Joints

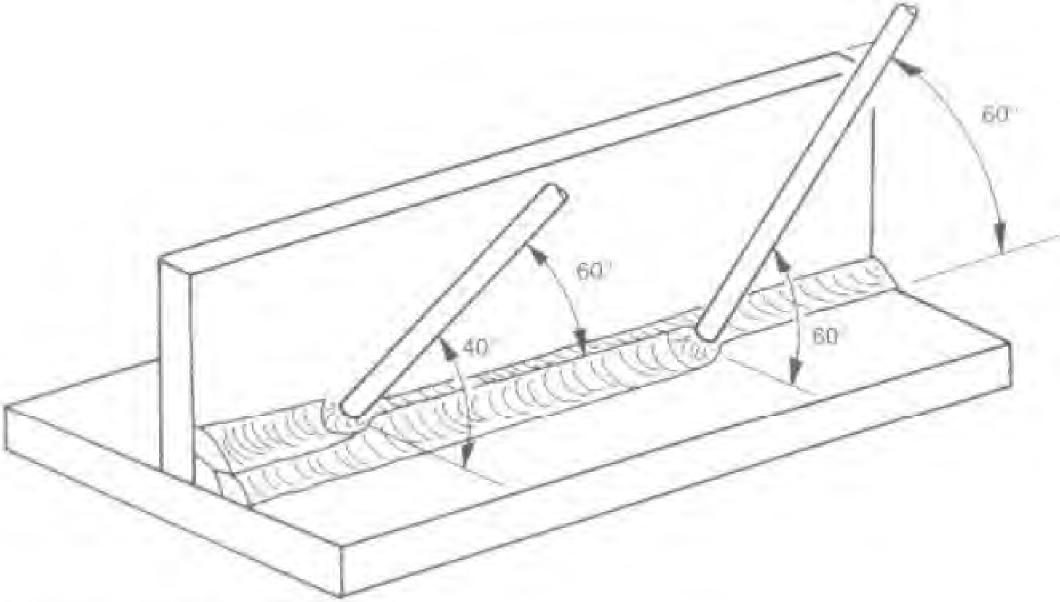
The weld holding lapped pieces of metal together is under a shear load which makes it much easier to break, and structurally less desirable than the same size weld under tension. Laps are not used as an easy alternative to butt welds but instead usually to 'thicken up' the material, for example in an area which is to receive a bolt.

It follows that a single pass is often all that is functionally necessary, but if full strength is needed the joint should be filled to the top edge of the lap. This edge should be melted away as little as possible so that the weld has a minimum cross section of a quadrant and blends smoothly with each plate without undercut.

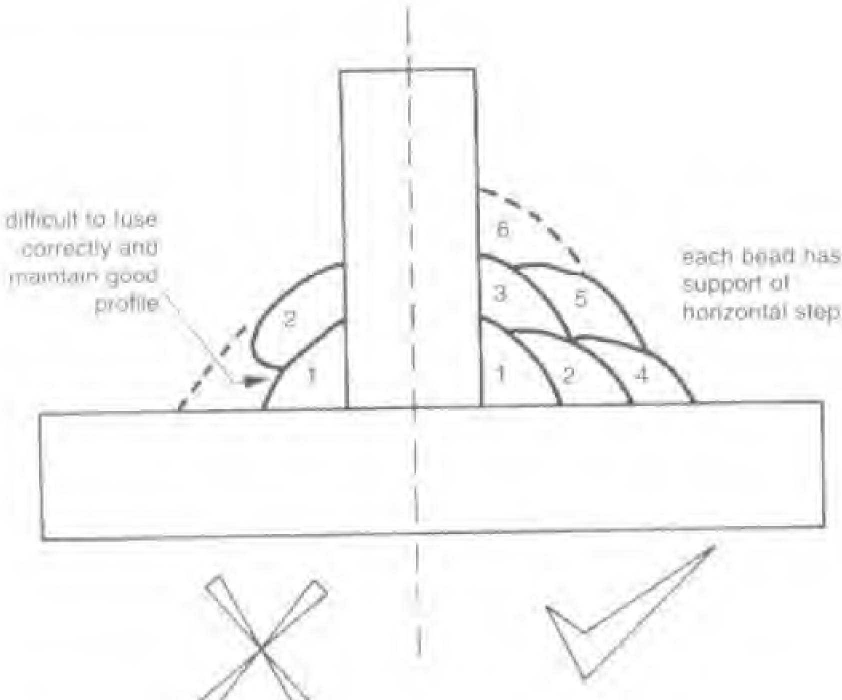
Lap joints are 'fillet' welded so the technique will be the same as for fillets, with the exception of the final pass at the top edge where the current needs to be reduced a little.

Outside Corner Joints

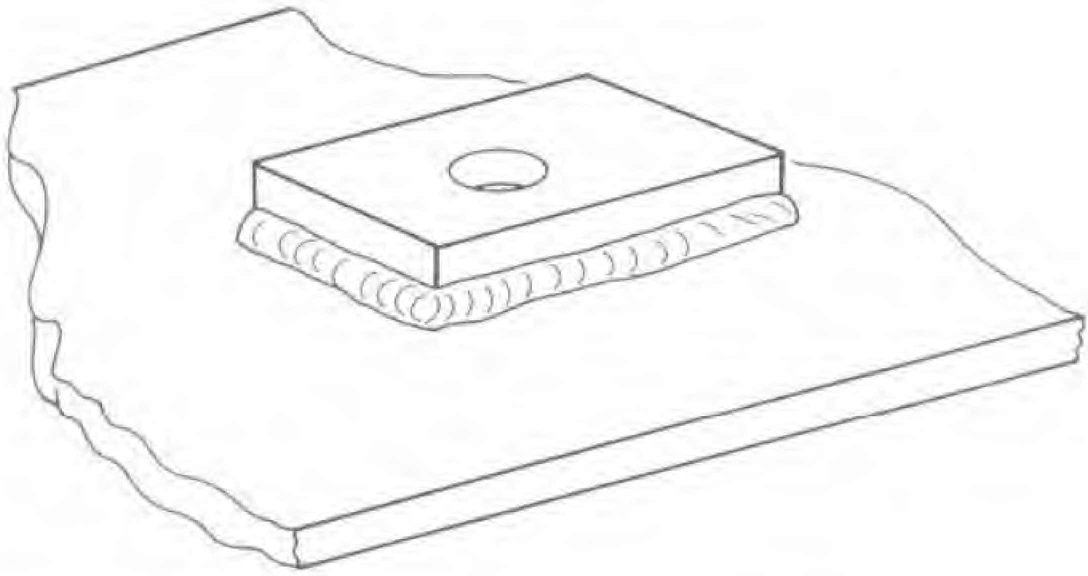
A 'close' corner joint is one where the plates touch without a gap. If full strength is needed then both edges are fully exposed but without overlap and set at 90 degrees to each other. They are then treated as fillet joints



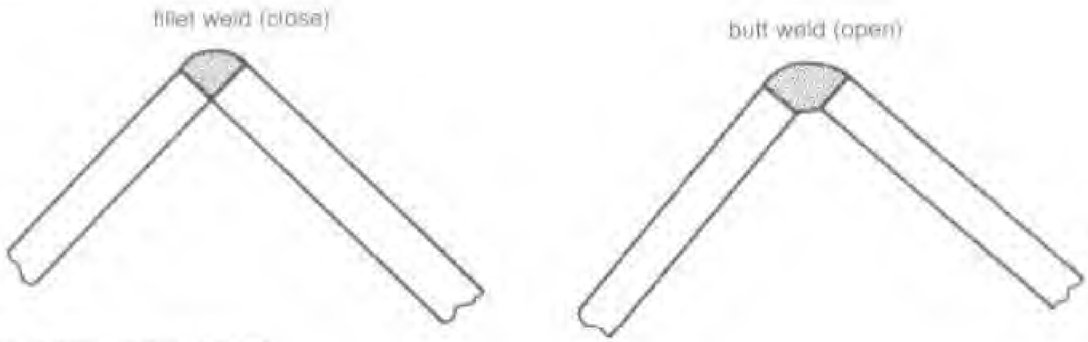
Fillet welding – second and third passes.



Multi-run build up sequence.



Typical situation requiring lap joints.



Close and open outside corners.

and are complete when the toes of the weld reach the outer corners to produce a quadrant profile.

Open corners are categorized as butt welds because the weld is made between two edges with a gap between them.

The main differences between close and open corners are:

1. An open joint has a greater cross-section that will need more weld metal and take longer to weld than a close joint.
2. The gap in an open joint makes it easier to obtain root fusion.
3. Gaps require special consideration; see Root Runs under Butt Joints below. Very wide gaps are difficult/impossible to join!

Butt Joints

Butt joints are ones between the edges of plates, which are usually in the same plane. Preparation of the edges varies greatly with thickness, accessibility of both sides and

strength required, and the joint may be close, open, or chamfered.

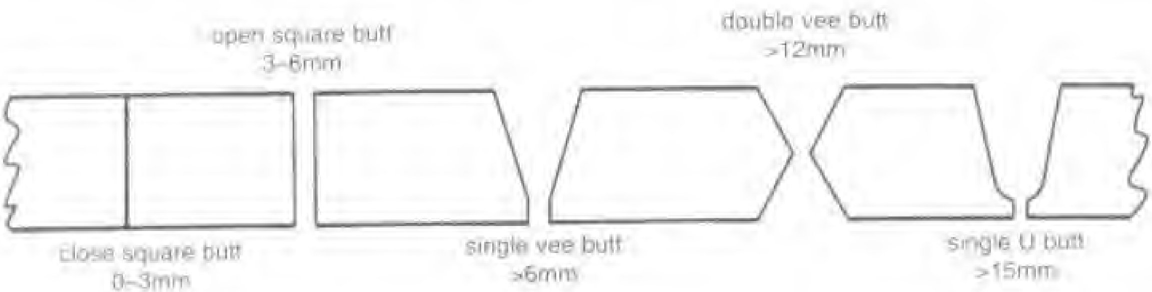
If 6mm plates are butted together, without a gap, and a single pass is made along the joint line then the weld will not penetrate through the full thickness. The strength may be adequate for many tasks, for example butting angle-iron together to produce the framework of a workbench, but the tensile strength will be well below that of plain 6mm steel. By either leaving a gap or by running a bead on both sides the strength is much improved.

To weld metal thicker than 6mm fully from one side the edges need to be chamfered at 30–35 degrees, to form an included angle of 60–70 degrees when placed together. This can be done with gas cutting equipment either by hand or with a profile machine, or mechanically with angle/pedestal grinders or nibblers designed to produce chamfers.

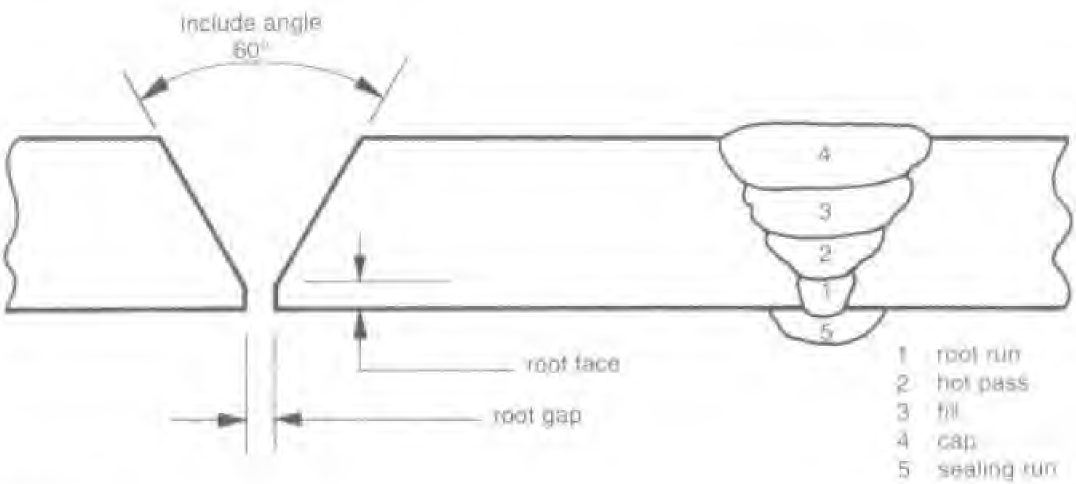
Finally the leading edge of the chamfer is removed to form a root face (see below).

Single V Butt Joints

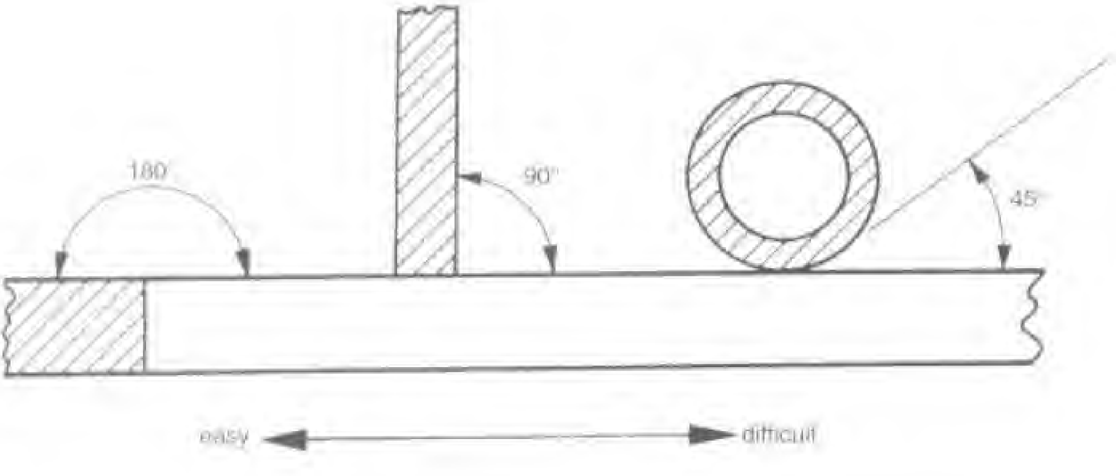
Single V butt joints are more difficult to



Various butt joint preparations



Parts of a butt joint



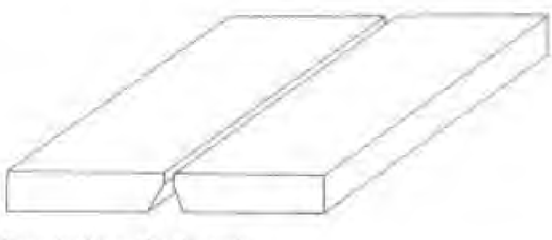
Effect of joint angle on ease of welding.

make than fillets because (a) the root run has to bridge a gap and (b) the joint angle of 60 degrees is more acute. Beads are made most easily on a 180-degree (flat) surface, and the transition to making 90-degree fillets will have illustrated that as the angle becomes more acute, both penetration and slag control become more difficult.

Root Runs

The joint is set up with a consistent root gap and root face of approximately 2mm. Tacking on the reverse side is easiest because the arc is at the surface rather than the base of the joint. It also enables the plates to be arranged flush and the gap even with greater ease. Tacking may have to be done from the face side if the other side is inaccessible or if it is a test weld for assessment to a welding standard.

In either case tacking across a gap presents its own difficulties. A small electrode is used on the lower side of its current range and the arc alternated from one edge to the other until the gap is bridged. This technique may



Easy tacking of butt joints.

need to be interrupted to allow the edges to cool if the tack sinks without bridging.

Tacks should be cleaned of slag and if necessary ground to a smooth concave profile to ensure they are completely fused during welding.

The root is made with a 'small' electrode, that is, a 2.5mm one on plate up to 6mm thick and for thicker plate a 3.2mm one. The arc is struck on the first tack and moved along the gap, melting away the edges to produce a key-hole exactly as in gas welding butts.

If the combination of prep angle, root face and gap, electrode size and setting, welding speed and electrode angle are correlated perfectly then simply progressing along the

joint will bridge the gap and produce a smooth underbead. It is much more likely that some sort of corrective measure will be necessary to keep root fusion under control.

If no key-hole forms and the weld metal bridges the gap without melting down into it then at this stage the only option remaining is to increase the current. Narrow gaps, acute V's and thick root faces are not conducive to root control.

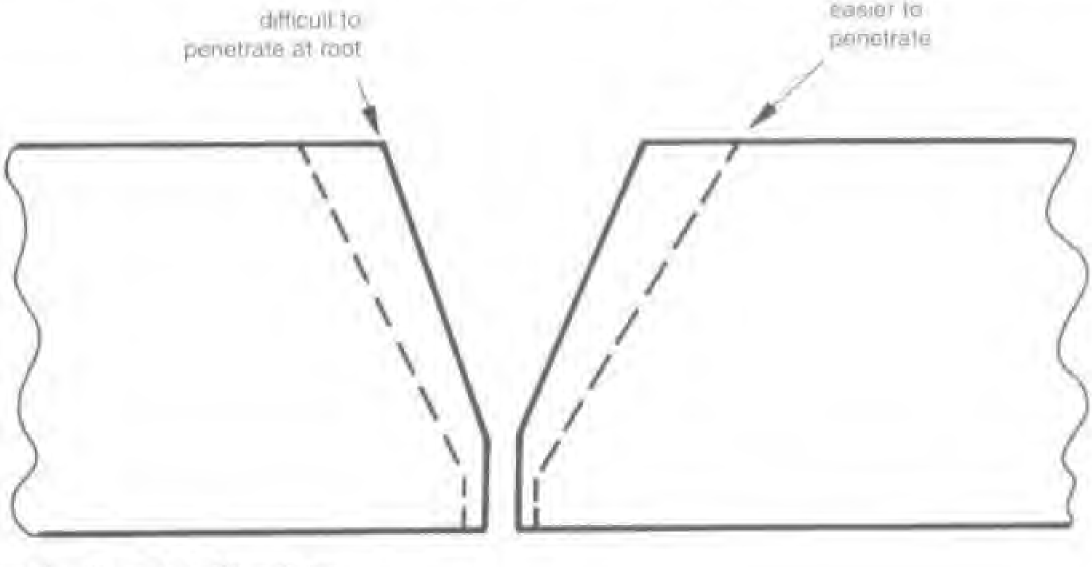
If the key-hole grows to the point where the weld metal is blowing through the gap without holding to the sides then one of three approaches can be used to improve control:

1. Weave transversely. The arc is moved from side to side, which removes heat from the thin edges to the centre. This should be done only just enough to maintain a small key-hole, so the need to weave may vary along the joint.
2. Weave longitudinally. The arc is moved on along the joint quickly to allow the weld pool to cool down, and then returned quickly back to the key-hole. The effect is a horizontal 'sawing' action.
3. 'Make and break'. As implied by its name, with this method the arc is extinguished, but not removed from the weld pool area. After the pool has cooled a little, say after 1–2 seconds, the arc is re-established and welding continued until it gets out of control again. This technique is particularly necessary when the volume of heat is well above that needed, that is, the gap is much too wide, the face too thin or the V too open.

In all three cases the idea is to allow some cooling of the weld pool to occur, but it is important to keep the weld pool liquid at all times. If, for example, transverse weaving is done too quickly then weld metal will cling to each edge, separated by a line of continuous slag down the centre.

Root Stop/Starts

Making fully fused, fault free V butt root



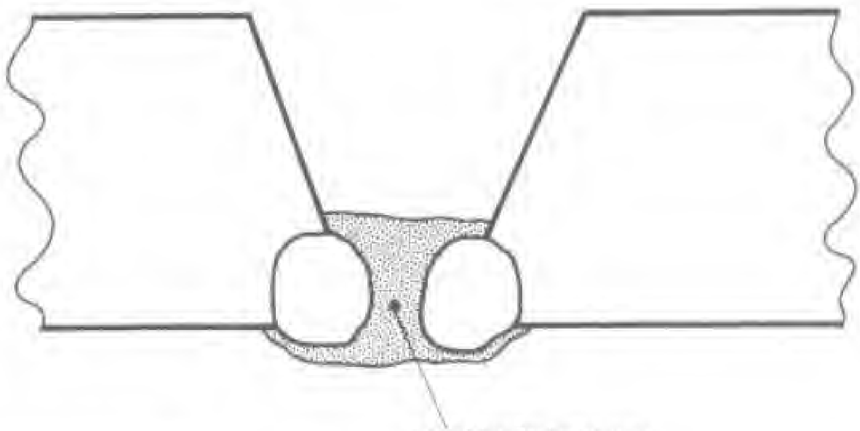
Effect of profile on ease of penetration.

runs with MMA demands much skill, and the most difficult part of the root is at the point where a restart is needed with a new electrode.

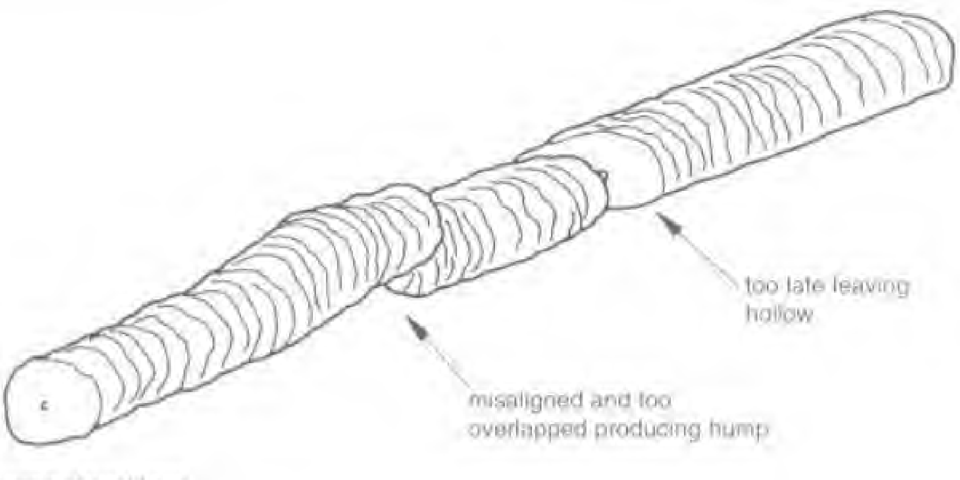
A sound restart is made much easier by ensuring that the key-hole remains at the end of the previous run. When the electrode is nearly consumed, remove it quickly without allowing the key-hole to fill in. Full penetration can then be picked up quickly with the next electrode.

To make perfect restarts the weld crater needs to be 'raked' back with an angle grinder or a hacksaw blade so that as the arc progresses down the slope it is fusing fully when it gets to the feathered edge of the old crater.

A compromise is to start the new bead about 20mm back on the old one, so that as it reaches the end of the old crater enough heat will be established to be penetrating well. The overlapped portion will be poorly fused and



Slag entrapment in a vee butt root



Poor restarting of weld bead

will need to be removed to ensure a smooth, even profile on which to place the next pass.

Filling up the V

Weld beads used in filling up the V are known as root, fill, and cap beads, with the cap or caps being the final layer and the fill those runs between the root and cap.

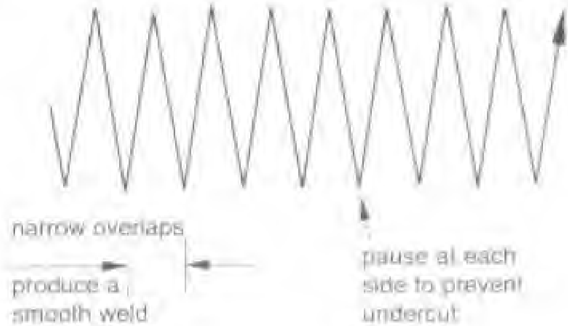
Fills and caps should be made with the largest electrode the joint will take, which is effectively a large groove once the root has been bridged. If the electrode used at any point is not large enough to bridge the V then a choice must be made between using stringers or weaved passes (but not both in the same weld).

When stringing, all beads are made in straight lines, which means that towards the top of the V there will be layers of weld beads deposited in the same manner as when weld padding.

When weaving, each layer is made in a single pass achieved by moving the electrode from side to side as necessary. A number of weave patterns exist but by far the most simple is to move in straight lines, across the V, pause to allow the arc to fill in, then straight back to the other side, a little further along the joint, then pause again, and so on.

Dealing with Faults

The completed weld must be welded through the full plate thickness, be fault free, and on



Weaving.

A MMA welded single-vee butt joint at various stages of completion.

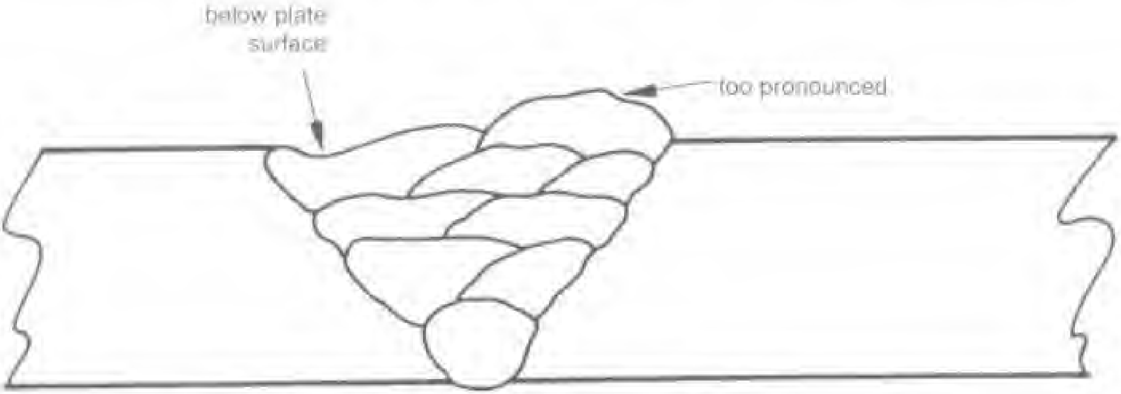
the surface be smooth and slightly pronounced, with no part of the weld below the plate surface. If faults become evident they must be removed as the weld progresses and not become permanent features. Common faults are:

1. Slag traps. These are pockets of slag left in and replacing part of the weld. Removal is carried out with a chipping hammer or chisel. If the slag is very deep, or if its removal produces a poor surface profile then grinding will be necessary.

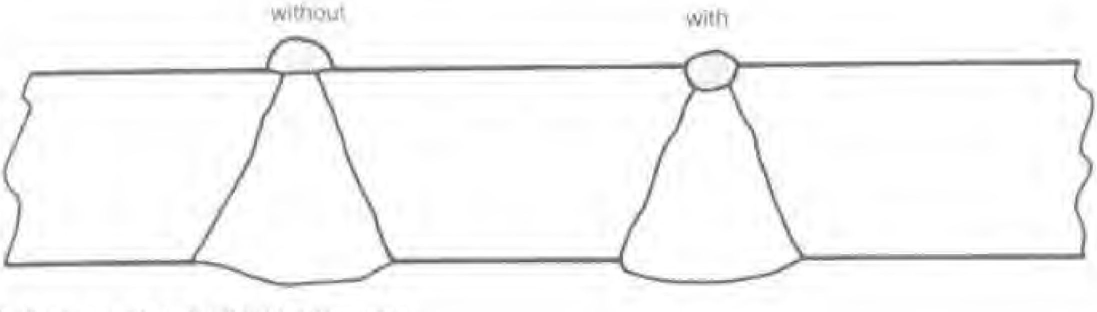
2. Poor Profile. Poor placement of weld beads can produce a profile that is too acute and deep for the next weld bead to penetrate to the bottom properly. The area must be opened out either locally or along the whole length to enable full fusion over the profile surface.

On the underside of the joint a small underbead of weld metal will be exposed along the entire length. If faults are evident, and access is possible, then a sealing run is made on this side to complete the weld. This is placed directly on the metal and should melt deeply enough to remove imperfections if they are shallow.

Larger faults will have to be removed by back gouging along the length, which can be done with a gas gouging nozzle, an MMA gouging electrode, an angle grinder or a bull nose chisel. A sealing run placed in this groove makes soundness of the weld more likely, and gives it a more blended profile.



Poor joint filling profile.

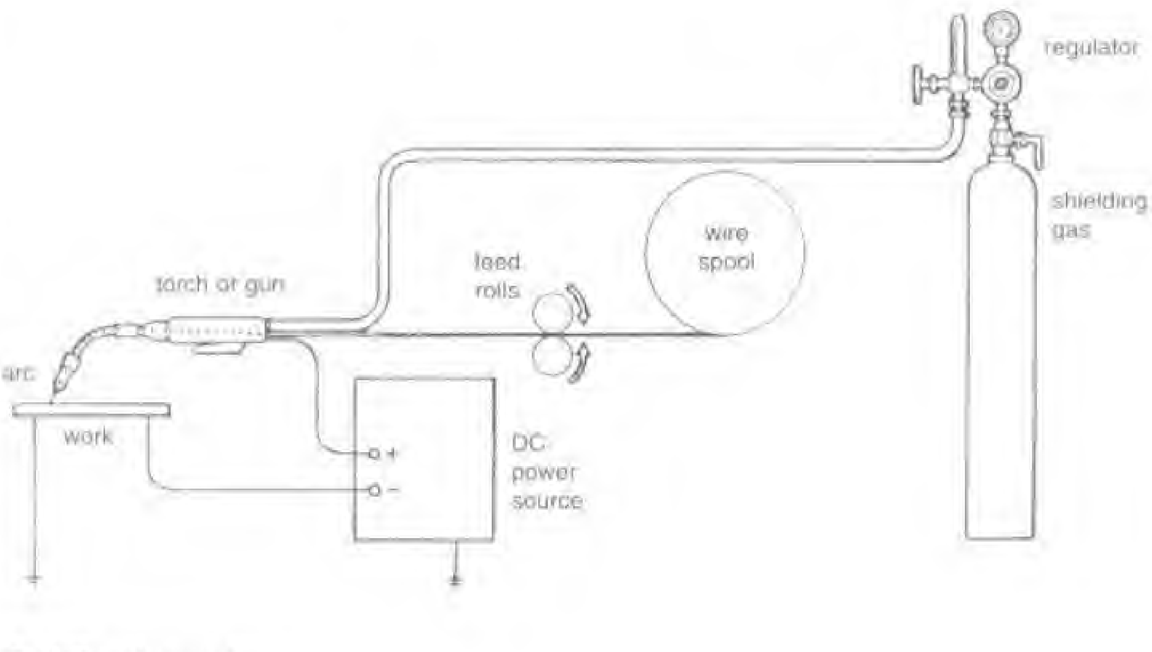


Sealing runs with and without back gouging.

5 MIG WELDING

This process is, or has been, variously known as CO_2, Sigma, MIG, MAG, and in the United States, GSMA. Each name revolves around the gas 'shielding' of the arc, highlighting the distinction between this process and the flux protection of MMA welding. The first gas used for steels was CO_2 but this has given way to argon mixtures. Sigma: Shielded Inert Gas Metal Arc, is historical and has now been shortened to MIG, which is the most widely used term, if not always accurate. There is often some chemical reaction between the shielding gas and the weld metal making Metal Active Gas (MAG) a more appropriate name than Metal Inert Gas (MIG). The American title Gas Shielded Metal Arc (GSMA) avoids this criticism.

Whatever the name, in this arc welding process the electrode takes the form of a fine wire, which is continuously fed to the arc, melted and transferred to the plate as weld metal. A shielding gas is also fed to the weld area to protect the weld metal by excluding the air.



The MIG welding circuit

The process is often regarded as semi-skilled because placing a weld bead in position smoothly is easier and to some extent automatic in comparison to MMA or gas welding. Setting up the welder to produce good results is more complex, however, and a good understanding of the parameters is necessary before the process's advantages can be exploited.

It finds application on all fabricational metals and on any thickness above about 0.6mm and is now by far the most prevalent manual welding process. It also lends itself very readily to automization/robotization and is widely used in this way, for example in motor car production.

An industrial MIG welding situation with wire feed unit mounted on an overhead boom

Since MIG welding is an arc welding process like MMA, consideration will only be given to those aspects where the difference is significant.

EQUIPMENT REQUIREMENTS FOR MIG WELDING

The following components make up MIG welding equipment:

1. Welding power source
2. Welding lead assembly with suitable liner
4. Welding torch with supply of contact tips
5. Spool of wire
6. Cylinder of shielding gas and a suitable regulator
7. Welding return
8. Welding earth

Power Source

All MIG power sources are welding rectifiers, with the electrode always DC positive and the work DC negative.

The choice is one of size, that is current output, and duty cycle. Very small DIY models supply about 90A and run only the smallest diameter wire whilst heavy industrial machines might supply 600A. Although even the largest wire does not demand more than 400A, a 600A machine can be used continuously at this level, that is, the duty cycle is excellent.

DIY machines are produced in a number of sizes up to 140A and run off a single-phase 13A supply. The purchase price is very low, but running expenses are relatively high because (i) the 0.6mm wire comes on a 1kg or 2kg spool which makes the unit cost high

compared to a standard 15kg spool, and (b) the shielding gas cylinder is of low volume and is either disposable or needs to be exchanged often – in either case the unit cost is again very high.

In the industrial machine category, 160A machines are the smallest, and rise in various increments to 450A and sometimes to 600A. The 160A size best suits car body repair work, with at least a 250A required for anything more than light fabrication.

Higher output machines not only offer a better duty cycle but also have a better voltage capacity, important for welding thick metal by 'spray transfer'.

A DIY MIG welding set with a small industrial cylinder.

The Welding Lead Assembly

This assembly is more complex than the MMA cables and is a polythene sheath containing:

1. The welding lead supplying power to the torch
2. A 'liner' through which the wire slides en route to the welding head
3. A gas hose supplying the welding head with shielding gas
4. Electrical wiring to the torch switch

The assembly is connected to the welder with a plug and socket known as a 'euro-connector', which makes all contacts simultaneously. When the large plastic retaining nut is unwound the only thing preventing the assembly being removed from the welder is the wire being fed through the system.

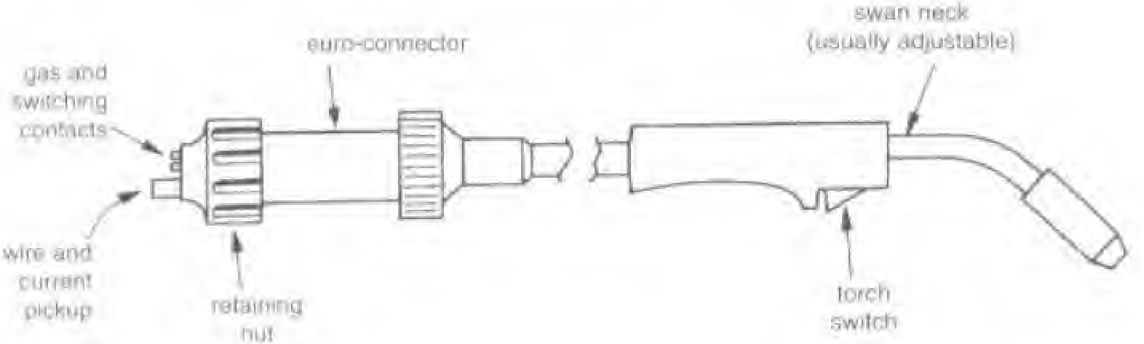
The Welding Torch

The important features of the hand held torch are:

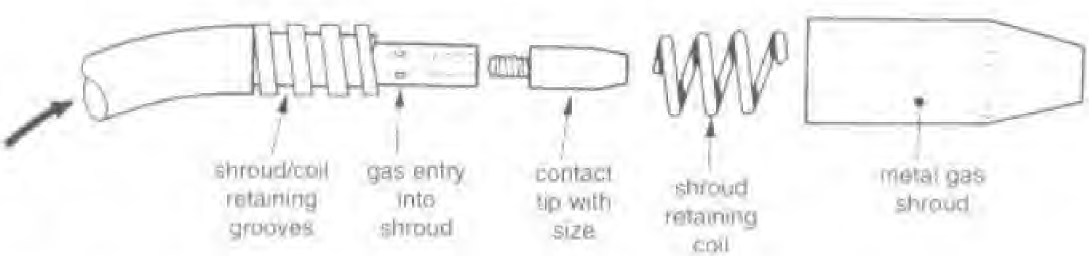
1. The switch, which is used to control the circuit (on/off), gas flow and wire feed rolls.
2. The 'swan-neck', which can be rotated to allow the operator to control the switch with either the fingers or the palm of the hand. It contains the tip holder, tip, and shroud.

MIG Welding Tips

The moving wire picks up electrical current at the tip as it exits the torch; it therefore needs to fit closely enough for this purpose but not so tight that it prevents movement. Tips are made of copper and come in sizes to suit each wire diameter.



The MIG welding lead assembly



The MIG welding torch

The tip is surrounded by a welding shroud, whose function is to direct gas towards the weld pool. The diameter varies with torch size, with larger ones supplying the increased demand for shielding gas. They are made of copper to withstand heat and general wear and tear.

Spool of Wire

Spool sizes are 1kg, 2kg, 5kg, and 15kg, the latter being the most common and economical. Standardized plastic spools have, with the exception of 0.6mm, layer wound wire, so that it unwinds smoothly. As with other consumables the selection is of type and size.

The range of MIG welding wires is much more limited than that of MMA electrodes, and they tend to be made to a high specification in order to be suitable for a range of materials. Thus wires are available for carbon steels, stainless steels, nickel alloys, aluminium and its alloys and so on.

There are four main sizes: 0.6mm, 0.8mm, 1.0mm and 1.2mm. The wires are all 'fine' but the range of leg lengths that can be produced is great, ranging from 2mm with a 0.6mm wire to 10.0mm with a 1.2mm one.

The Wire Feed Unit

The unit may be housed within the welding set and an integral part of it, and exposed by removing a panel from the side or top of the machine.

Alternatively it may be a separate unit connected to the welding set only by welding

Metal Thickness (mm)	Wire Dia. (mm)	Butt			Fillet		
		Current (amps)	Arc voltage	Wire feed speed (M/min)	Current (amps)	Arc voltage	Wire Feed speed (M/min)
1.6	0.8	80	19	3.2	90	20	4.0
2.0	0.8	90	20	4.0	110	21	5.5
3.25	1.0	140	22	7.0	160	23	7.5
6.0	1.2	240	25	7.5	260	27	7.8
9.0	1.2	270	27.5	7.9	280	28	8.0
12.0	1.2	2000	29	10	310	29	10.5

Typical MIG welding conditions for mild steel

leads and gas hose. The advantage of separate units is that they can be mounted on a radial boom above head height and over the welding operation. This reduces the likelihood of fouling of the leads with the work as it is being assembled, giving the operator much greater freedom of movement. It also enables welding to be done at greater distances from the welder without lengthening the welding lead or the distance the wire has to be pushed.

Shielding Gas

A shielding gas is supplied to the welding area to displace the air and provide a controlled atmosphere. Only aluminium and nickel and their alloys are best welded with a totally inert gas. All other metals use a mixture of gases, typically argon based but with varying additions of carbon dioxide, oxygen, helium or hydrogen.

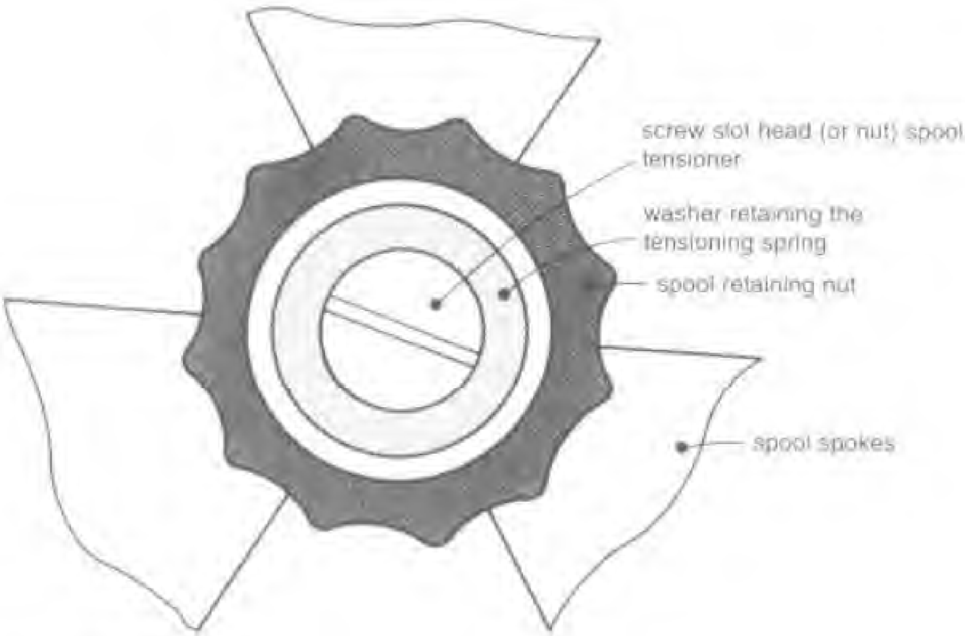
Disposable or small rechargeable canisters are expensive to run as stated earlier. Industrial cylinders vary from 2,500 litre ones, which are very easy to wheel about when mounted on a welder with castors, to 10,000 litres; this size costs the same per litre as the 2,500 litre size and has the same monthly rental charge, but will not incur a gas sale transaction charge or disrupt work flow as frequently.

The gas regulator used must be one designed for use with the shielding gas. A single-stage one is satisfactory but should ideally have a delivery gauge to provide a guide to gas flow. The only way to know precisely how much gas is flowing is to fit a flowmeter, but for most work this is not a necessity.

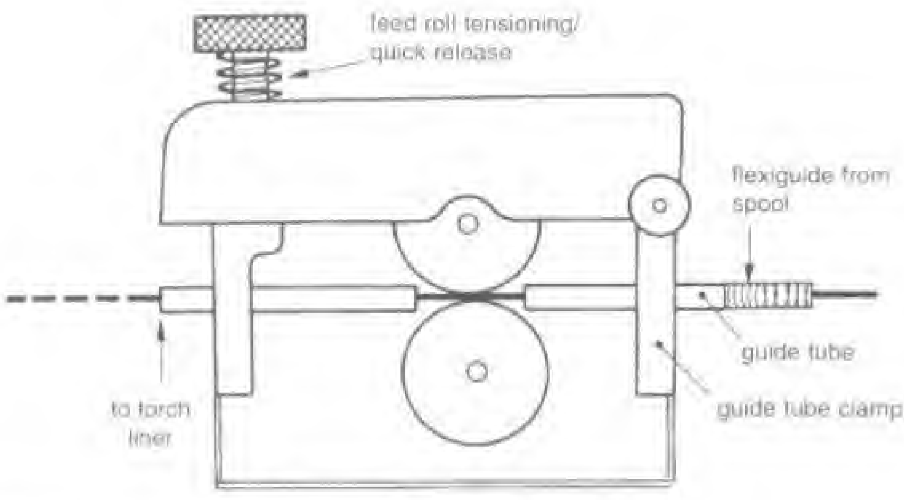
MAINTAINING/REPLACING EQUIPMENT

Welding Plant

Modern welding rectifiers are very reliable, and with the exception of a cooling fan have no moving parts. The only maintenance possible or necessary is periodic removal of dust and metal particle build-up inside the machine. This is done with compressed air but ensure that (a) the air is dry and (b) goggles and a dust mask are worn.



The spool tensioning mechanism.



The wire feed rolls.

Welding Lead Assembly

Excess wear in the liner produces erratic feeding of the wire, which indicates need for replacement. To remove it, extract the wire from the liner, disconnect the euro-connector at the machine and withdraw the liner from the connector.

The liner is either a helically coiled flexible metal tube or a Teflon tube; the latter has a shorter life but unlike the metal tube does not clog with chafed wire particles, especially with soft aluminium wire.

Welding Torch

The welding tip wears rapidly and then ceases to transfer current to the wire correctly. Replacements of the same size (stamped on the outside), same thread and physical size, are screwed in and 'pinched' tight.

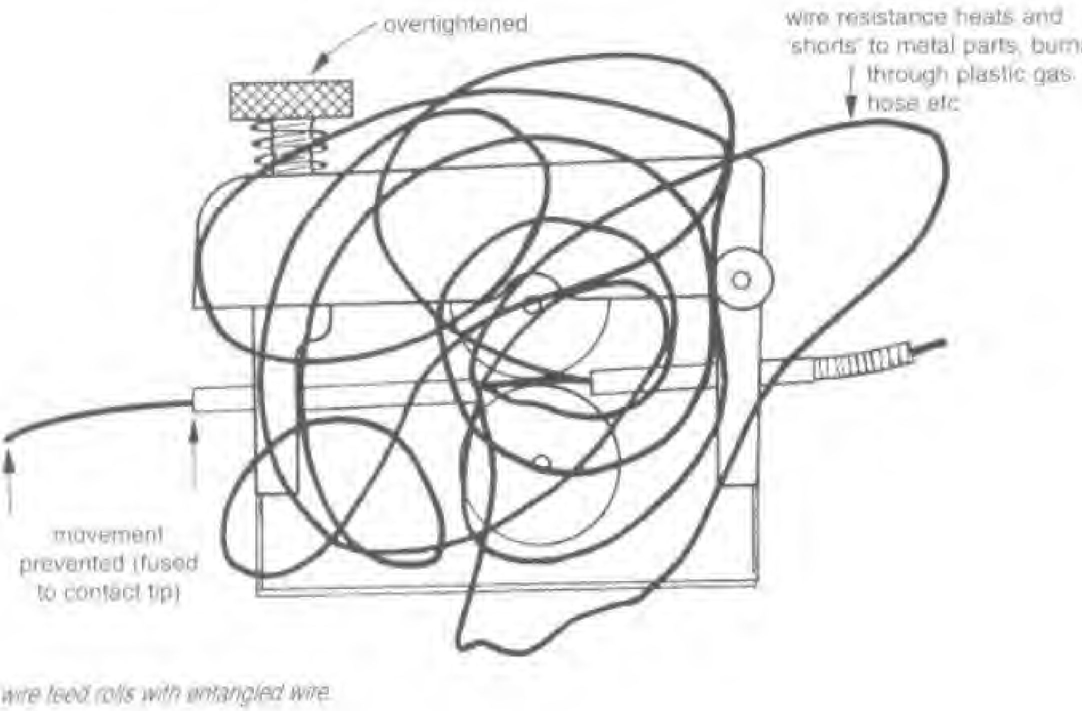
Shroud

These are a sliding fit over a heli-coil and may require replacement because they are too dented or worn to direct gas properly, alternatively, the coil may cease to grip the shroud.

ASSEMBLING THE EQUIPMENT

Loading the Spool

The spool is loaded ensuring that the drive peg on the wire feed unit is located in a spool drive hole. It must be put on the right way up/around so that the wire feeds directly and smoothly into the feed rolls. The spool retaining nut is attached and a check made for ease of rotation. The spool must rotate freely but not to the extent that it overruns



The wire feed rolls with entangled wire.

and inwards when the feed rolls stop. This is adjusted with a tension spring located in the spool drive axle.

Feeding the Wire

The wire is drawn off the spool and pushed through the liner by wire feed rolls which form part of the feed unit. One roll is smooth faced while the other has a groove to suit the wire diameter. Rolls typically are designed to drive two wire sizes, either 0.6mm and 0.8mm, or 1.0mm and 1.2mm and the roll must be mounted correctly in order to make use of the correct groove.

A clean, kink-free wire end is fed into the roll inlet guide tube, run through the opened rolls and into the euro-connector guide tube. The open roll is then closed onto the wire, gripping it in the groove.

Feed rolls vary greatly but all will have provision for adjustment of pressure. The rolls must grip the wire well enough to pull a full 15kg spool, but if the wire is prevented from flowing for some reason then ideally the rolls should slip on the wire. Forceful continuation of wire feed would result in the wire breaking out of the roll assembly and building up in a tangle like spaghetti. If this happens the tangled wire has to be cut out and the wire refed before welding can continue.

The wire must be kept taut at all times between releasing its end from the mounted spool and gripping it in the rolls, otherwise it will unwind and get tangled to the point where it will not feed properly.

The wire now needs to pass through the liner and torch, and this is achieved by pressing the switch on the torch with the welder turned on. Whilst waiting for this to happen do not hold the torch close to the eye or have a finger over the torch end. The wire is less likely to snag if the tip is off at this stage, so finally the tip is slipped over the exposed wire and screwed home.

PREPARING TO WELD

The wire type and size are selected and installed and the gas type and flow set at this stage before making electrical adjustments.

Setting the Gas Conditions

Gases for steels are argon based, with an addition of 2 per cent oxygen and between 5 and 20 per cent carbon dioxide (CO_2). Higher CO_2 levels increase the heat/penetration in the arc but also produce more spatter. Five per cent is recommended for steel up to 5mm thick, and above this thickness 20 per cent. A universal shielding gas, available for some years now, is one with 12 per cent CO_2, which produces good welds through the full range of thicknesses.

The amount of gas needed to provide effective shielding of the weld pool is determined by the shroud diameter, and will increase as welding gets heavier. Tables of flow rates are only useful if the flow (volume rather than pressure) can be measured.

The lowest setting possible consistent with making welds free of oxide or porosity should be selected; this can be assessed by "listening" to the gas flow whilst working and then reviewing it in the light of weld quality. Factors influencing the volume of gas needed are draughts, which disrupt the shielding, and joint type. Fillet joints tend to contain the gas whilst outside corners allow it to escape.

Setting the Electrical Conditions

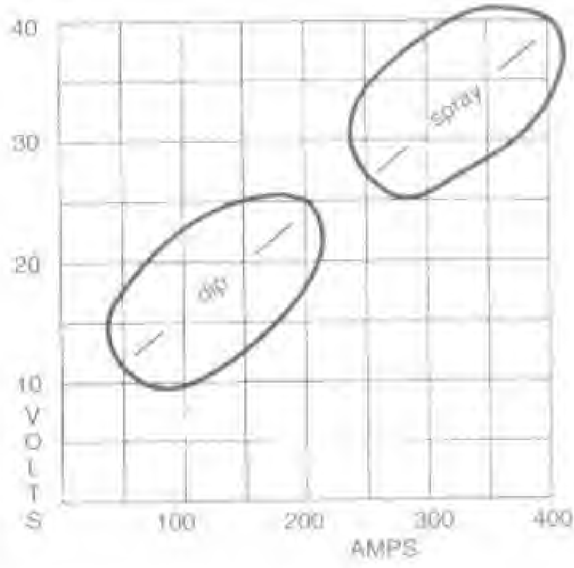
The three main electrical variables are:

1. Arc voltage, which controls the type of metal transfer, arc length and weld profile.
2. Wire feed speed, which controls the current as well; one knob turning each up/down, and determines the weld size.
3. Inductance, which determines the rate of the current rise through the wire.

Obtaining satisfactory welding conditions requires careful balancing of all three parameters, and changing any one will have an effect on the other two, which may then also require adjustment to produce a stable arc. The approximate voltage should be set first.

The two distinct ways in which the wire melts and transfers to the weld pool are known as dip transfer and spray transfer. The mode of transfer is determined by a combination of voltage and current set for a particular wire. For a given wire size dip transfer is obtained at low current/voltage settings, whilst, providing the welder has sufficient capacity, typically 250A or more, spray transfer is obtained at high voltage/current levels.

Initially the voltage is set at roughly the right level to provide the transfer required, and checked with the voltmeter on the machine (press the volt test button or the torch trigger) or by guesswork based on experience.



Welding conditions for dip and spray transfer.

DIP TRANSFER

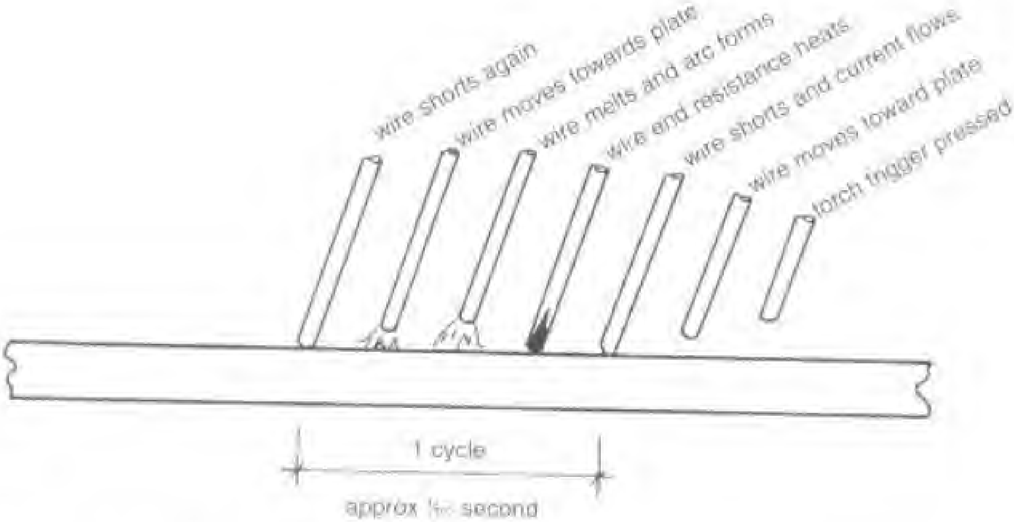
The arc goes through the following cycle about 100-120 times per second.

1. The wire advances to touch the plate and complete the circuit.
2. The wire heats due to the high current passing through it.
3. The end melts and transfers to the metal surface.
4. An arc is established.
5. The wire advances and touches the plate again.

This process is known as dip transfer because the wire keeps dipping in the pool. Although it appears to be constant, the arc exists for only part of the time, with the wire 'short-circuiting' the rest of the time. It is a fairly 'cool' method of welding, good for thin metal and welding vertically and overhead.

Effect of Inductance

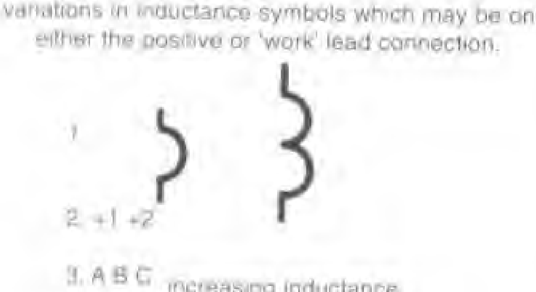
If the current increases too rapidly during



The dip-transfer sequence

the period it is short-circuiting, the wire will melt so rapidly that it would explode out of the arc, rather like an electrical fuse blowing, producing much spatter and very little weld metal. If the current rise is too slow then the wire will stub or freeze in the weld pool.

Control of the current rise/heating effect is ensured by having an appropriate inductance in the circuit. On smaller machines this is fixed, whilst larger ones may offer a choice of two or three settings. These are rarely labelled but older machines may identify them as 'choke' or 'reactance'.



Identifying inductance settings

High inductance gives a lower short-circuiting frequency and relatively 'hot' welding due to the longer arcing periods between short-circuits. The arc will be quieter, and produce less spatter and smoother welds than lower inductance settings.

The higher short-circuiting frequency of a low inductance setting produces more noise and spatter and a more pronounced ripple on the weld, but it will be cooler.

High inductance settings tend to be used on thick metal whilst low inductance, and unfortunately more spatter, will suit thin sheet and positional welding.

Setting Up Dip Transfer

The three requirements in setting up dip transfer are:

1. Producing a stable arc with the size of wire in use.
2. Supplying the right amount of weld metal.

3. Supplying the right amount of heat for adequate fusion.

MIG welding is notorious for being able to satisfy the first requirement, and by juggling the welding speed the second one also, but badly failing to produce fully fused weld metal.

Whilst approximate voltage/wire feed speeds can be recommended the final settings can only be established by producing a range of welds, ideally in a simulated situation, and arriving at optimum conditions through trial and error.

Arc Voltage Adjustment

With very low settings the arc is so short that the wire may stub, pushing the hand back, and be very erratic. Increase in voltage lengthens the arc to the point where it becomes stable, but further increase results in the wire end melting in a ball, this globule eventually transferring to the pool. This is occasionally useful and is known as globular transfer. As the voltage is increased the high, narrow weld profile progressively gets wider and flatter.

Wire Feed Speed

The speed at which the wire is fed determines the size of weld, that is, the amount of metal deposited. A larger weld is produced by turning the wire up but this will also shorten the arc because the voltage/current balance has been altered. It is possible to change either the wire speed or the voltage a little without changing the other, but if the arc is lengthened significantly then an accompanying increase in voltage is necessary to keep the arc stable whilst making the larger weld.

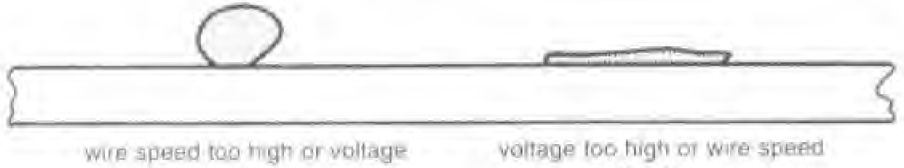
Smaller welds are of course made by turning the wire speed down, and re-balancing the voltage as necessary.

The degree to which the wire speed/voltage balance can be raised or lowered is limited by the stability of the arc. Settings which are simply too low for the wire produce a weak arc that fuses poorly. Very high settings produce an arc that is overly forceful, agitating and pushing the weld metal out of place.

Changes are required to a smaller and larger diameter wire respectively, so that they operate at current densities that are stable.

Welding Speed

The weld size can be varied by changing the speed of travel but again there are limitations. Very large weld beads can be made in a single pass and may appear to be good and sound from the surface but may turn out in reality to be far less effective than supposed. In a destructive test, or if failing in service, the joint would have a fracture surface exhibiting lack of fusion in the root and the lower side wall of the joint. This occurs



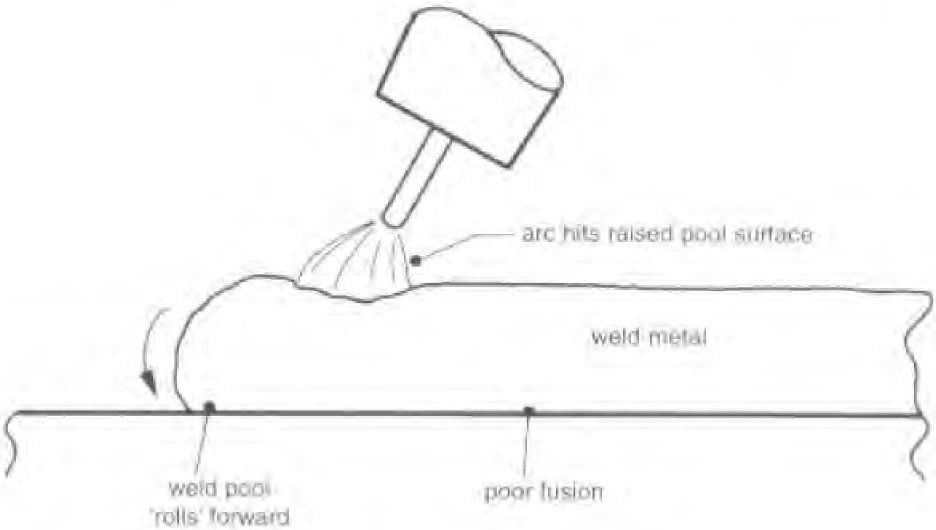
Balancing wire speed and voltage from appearance of weld bead

because the arc is between the wire and the elevated surface of the weld pool, with the pool acting as a buffer between the arc and the joint surface.

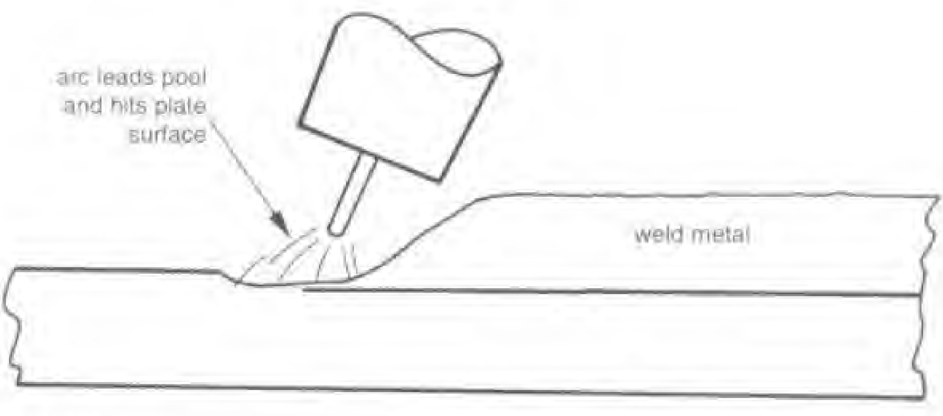
Welds made very quickly have a very reduced cross-section and many passes are needed to build up a strong enough profile. The weld should be sound, with satisfactory fusion, but may be brittle as a result of the fast cooling rate.

Passes should be made slowly enough to be controllable and of reasonable cross-section but quickly enough for the wire to 'lead' the pool: the intention is to arc between the wire and the plate, not the wire and the pool.

If the bead is the size desired but had to be made at a speed which produces lack of fusion, then the wire should be changed for a larger one, so that the same amount of metal can be deposited at a faster speed. This may



Welding too slowly.



Welding at the correct speed.

of course exceed the capacity of the welder, or a 1.2mm wire may already be in use, in which case a number of smaller runs should be used in preference to a single large one.

The difficulty arises in recognizing that lack of fusion is occurring, so professional training and quality control are essential to ensure sound welds.

SPRAY TRANSFER

With voltages above 25V the wire melts differently. Once the arc is established, it is permanent; that is, the wire does not dip into the pool and short-circuit. This mode of transfer is therefore unaffected by inductance setting.

At high voltage/wire feed levels fine molten droplets form at the end of the wire and are sprayed across the gap, and since the arc is continuous this method is suited to making large, well-fused welds on thick metal, but is too hot for thin or positional work.

Setting Up for Spray Transfer

Spray transfer lends itself best to 1.0mm and 1.2mm wires and high metal deposition rates. The very hot, fluid weld pool can only be controlled on flat and horizontal work, but is not as susceptible to the lack of fusion associated with dip transfer.

Voltage/Wire Speed Setting

If the voltage only is increased then the arc lengthens ultimately to the point where it burns back onto the tip, but if the increase in voltage is accompanied by a significant increase in wire feed speed, then spray transfer is obtained. The arc does not crackle but burns steadily and there is very little spatter after initial arcing. The arc is very intense and particular attention should be paid to protection against arc burn/eye.

FOR BOTH TYPES OF TRANSFER

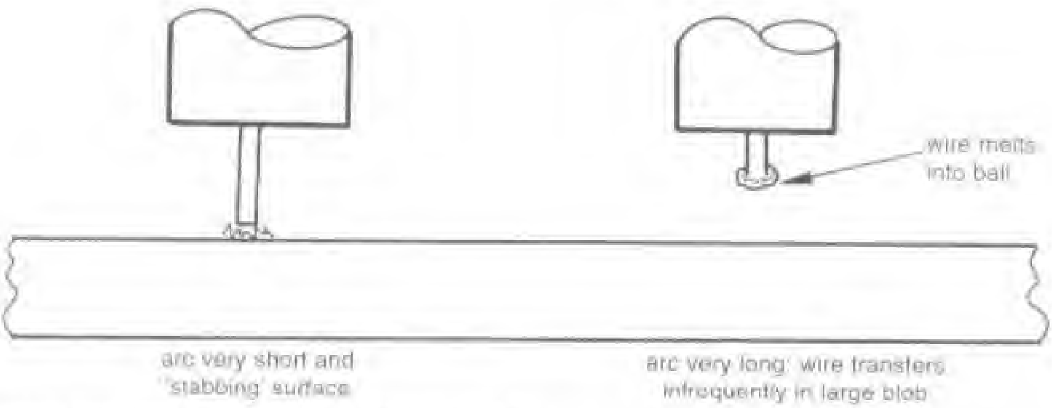
Initially the voltage is set roughly to provide the type of transfer required and at a level to suit the wire diameter: larger wires require higher voltages.

It is important to set the wire 'high', and slowly reduce it, because if it is low (and the voltage high) the wire will melt back onto the tip instantly. One second of attempted welding is then followed by a period of 3–5 minutes of maintenance! The fused tip end may mean the tip has to be replaced, and if the torch switch was not released quickly then the wire may have burst out of the wire feed roll mechanism. Both situations are frustrating, testing the welder's patience and wasting time.

It will be apparent that the arc length can be changed by an alteration to either the voltage or the wire feed. Which one needs adjusting is determined by the size of weld being produced. If it is satisfactory, but the arc long, then the voltage should be turned down. If the weld was a little small and the arc long then the wire should be turned up.

It is also apparent that good MIG welding conditions are obtained by carefully balancing five variables, ie:

1. Wire size
2. Voltage
3. Wire speed
4. Welding speed
5. Inductance, and to some extent, shielding gas.



Balancing wire speed and voltage from appearance of arc.

Therefore guides on each of these variables for a particular metal thickness/type of joint can by definition only be guides, and welds of identical quality can be made using parameters which are not fixed absolutely.

FINAL PREPARATION

The arc is far more sensitive to heavy oxide, rust, paint, oil and so on than in MMA welding, and may fail to strike at all. It can accommodate standard mill scale on hot rolled steel but for quality work all contaminants must be removed by grinding or degreasing.

Screens used in the welding area should be positioned to protect passers-by but also to reduce draughts at the welding point.

The following accessories should be available:

1. Welding screen/helmet. Light radiated from the MIG arc is not diffused by fume as it is in MMA so for a given current level the filter glass needs to be darker so the arc can be viewed comfortably, especially as the glare from bright steels or aluminium is greater still.

2. Anti spatter spray/jelly. Proprietary fluids are available which prevent spatter sticking to and building up inside the nozzle. They are applied either by aerosol or by dipping into a jelly. Spatter build up disrupts gas flow and will eventually bridge to the shroud, making it live and arc when the torch switch is operated. Spray used on the metal surface will reduce spatter sticking to it, but it then needs to be removed with a solvent before the surface can be finished with paint.

3. Side snips. Before recommencing welding the wire end must be snipped to adjust its extension beyond the shroud and to provide a clean unoxidized end that will strike more easily. The wire cannot be withdrawn through the liner for exchange without removing the 'balled' end, and snips are essential if wire snarled up in the feed rolls has to be cut out and removed.

MAKING A WELD BEAD

The wire only becomes live when the torch switch is depressed. This enables the starting point to be located with precision and safety,

Some MIG welding accessories.

and with the wire already in contact with the metal if necessary.

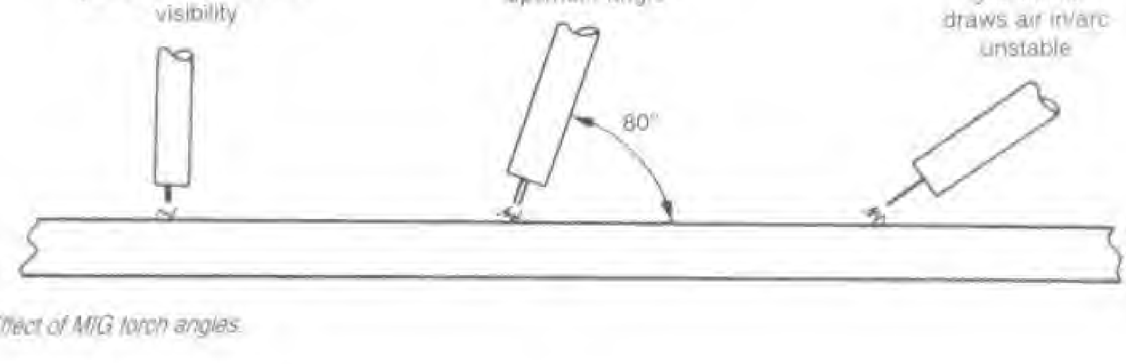
The torch angle is held very close to vertical. It should point in the direction of travel, at about 80 degrees to ensure maximum use of the gas shielding. A too acute angle causes:

1. Ingress of air into the shielding gas, drawn in by the moving gas. This can also happen if the gas flow is set too high and results in scummy welds and porosity, often visible on the surface.

2. An erratic arc when, as the torch progresses the contact tip/metal surface distance changes suddenly and the arc takes time to readjust. Squarer angles reduce sensitivity to changes in distance or slightly jerky movement of the torch.

The Self-Adjusting Arc

It will be found that if the contact tip height is varied smoothly it makes only a minor difference to the length and stability of the



Effect of MIG torch angles.

arc. It is this self-adjusting feature that causes MIG welding to be considered a semi-skilled process, but whilst it is quite easy to use, it is much more difficult than MMA to set up and provide guaranteed weld quality.

The behaviour of the arc is illustrated below. If the arc length is increased because the torch is moved further from the plate or a cavity is passed over, the arc voltage goes up; that is, there is a larger difference in potential, or a greater EMF is required to get current to cross the gap.

Since the power of the arc is constant, as the voltage goes up the current reduces and the wire melts more slowly, restoring the original gap.

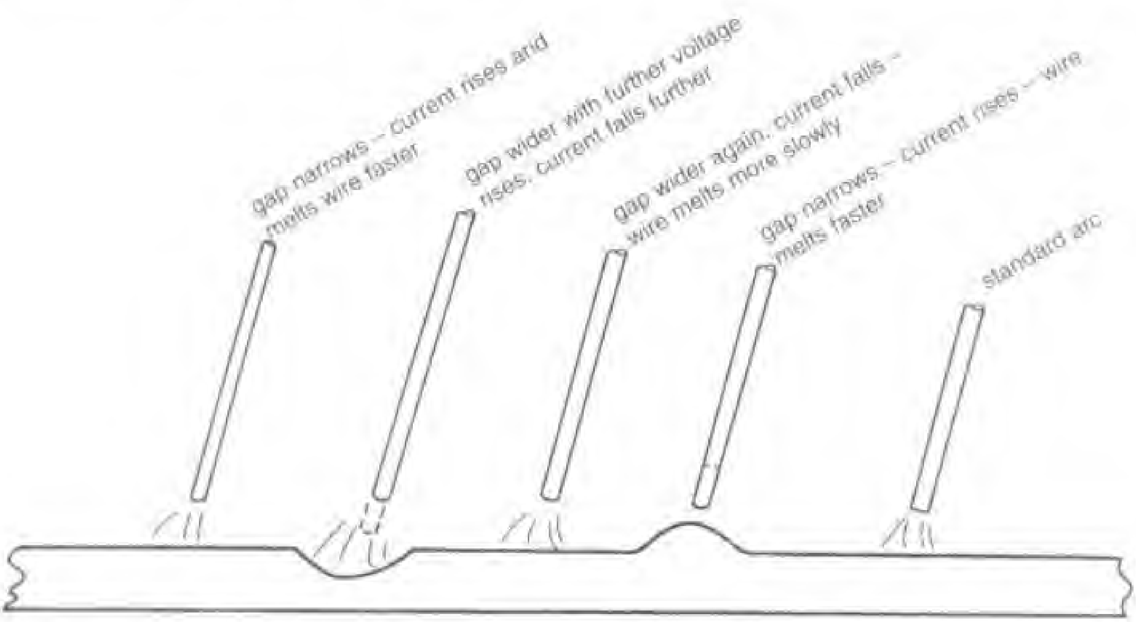
This relationship may have been experimented with in MMA welding but the electrical characteristics of MIG welders are such that they respond very sensitively and quickly to voltage change. Passing over a hump of some sort or closing the contact tip distance will lower the voltage, increase the current and cause the wire to melt more quickly until the arc length readjusts.

Finishing a Weld Bead

The arc is held in the end crater for 1–2 seconds and then extinguished by releasing the torch switch. Holding the torch in position a further few seconds will help prevent oxidation of the crater through sudden loss of gas shielding.

Since the existing settings on the machine are fine and may be appropriate for the next task, there is no point in zeroing the wire feed and voltage switches. Shutting down is therefore simply a matter of:

1. Turning the welding set off at the isolator.



The self-adjusting arc.

2. Closing the gas cylinder valve.
3. Unwinding the regulator pressure adjustment knob.

MAKING WELDED JOINTS

Much of the skill in making good joints is in setting the welder correctly and it is useful to have a similar joint on which to practise and evolve the best welding conditions before commitment to the actual task. This practice is essential until the operator has both experience and familiarity with the machine.

Tacking

Tacking with MIG is very much easier than with either gas or MMA welders. When tacking with gas the joint edges can expand some distance apart before the edges have been raised to melting point and this must either be prevented or allowed for.

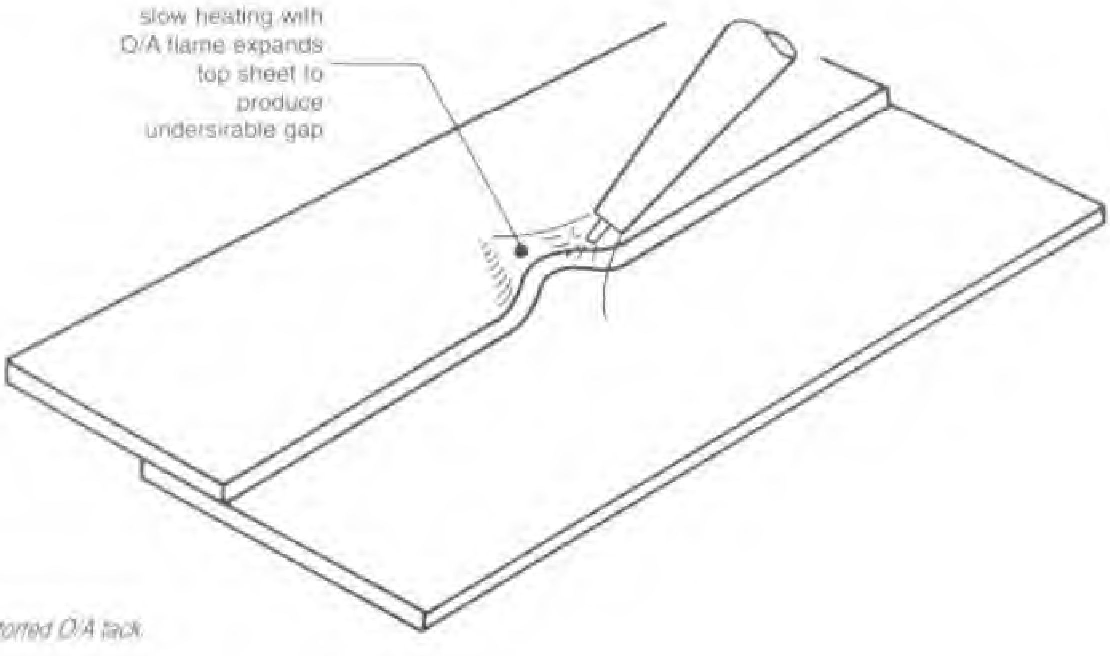
MMA tacks are made 'instantly' but arc striking can be difficult, leave unwanted flashes over the metal surface, or knock the joint out of position if it is not restrained well enough.

When tacking with MIG the wire can touch the point at which the tack is required, and on pressing the torch switch be made very quickly. Like MMA tacks some progress along the joint is necessary to get the tack to blend in rather than build up in a blob.

Fillet Joints

Stringer beads are deposited with a slope of 80 degrees and a tilt of 45 degrees, with negligible allowance for either gravity or dissimilar thicknesses.

The leading edge of the weld pool must be observed to be fusing right into the root whilst the trailing edge should be forming



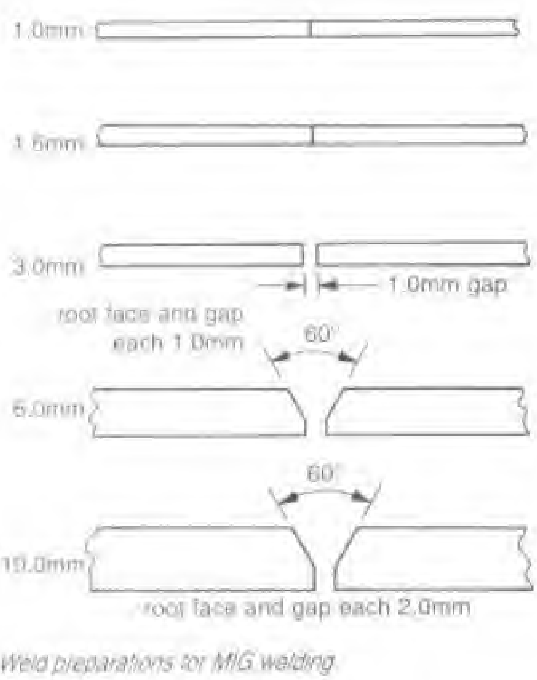
A distorted O/A tack

the desired profile. Welding requires constant assessment of weld pool shape and size, and immediate corrective action taken if necessary. If automatic welding is like using a motorway – establishing optimum conditions and fixing them – then manual welding can be likened to driving a car along a country road, where a constant series of corrections is necessary.

Butt Joints

Butts can be made with ease in sheet 1.0mm to 3.0mm thick in a single pass with a gap of 0.75 × thickness but no edge preparation.

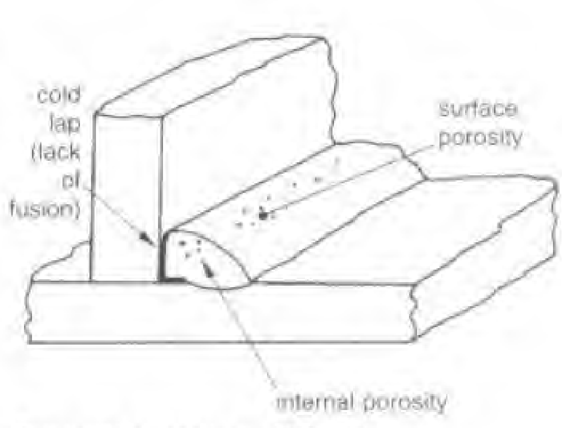
For plate butts, a 60-degree V is used with a root face and root gap of 1.5mm. This is less than with MMA, but the weld is split into a root and cap in the same way, to allow maximum attention to be given to penetration with the first pass, and weld profile with the latter.



Weld preparations for MIG welding.

FAULT FINDING IN MIG WELDS

Fault	Cause
Scattered porosity	Gun at acute starting angle Build-up of silicate slag Oil or other deposits on metal
Heavy porosity	Windy conditions Not enough shielding gas No gas turned on
Cold lapping	Wire feed too high Voltage too low Welding speed too low Arc not on leading edge of pool
Unstable arc	Voltage either too high or too low Clogged contact tip Wire feed erratic Poor return connection
High bead with overlap	Voltage too low Wire speed too high
Flat rough weld	Voltage too high



Porosity and cold lap in a MIG weld.

6 TIG WELDING

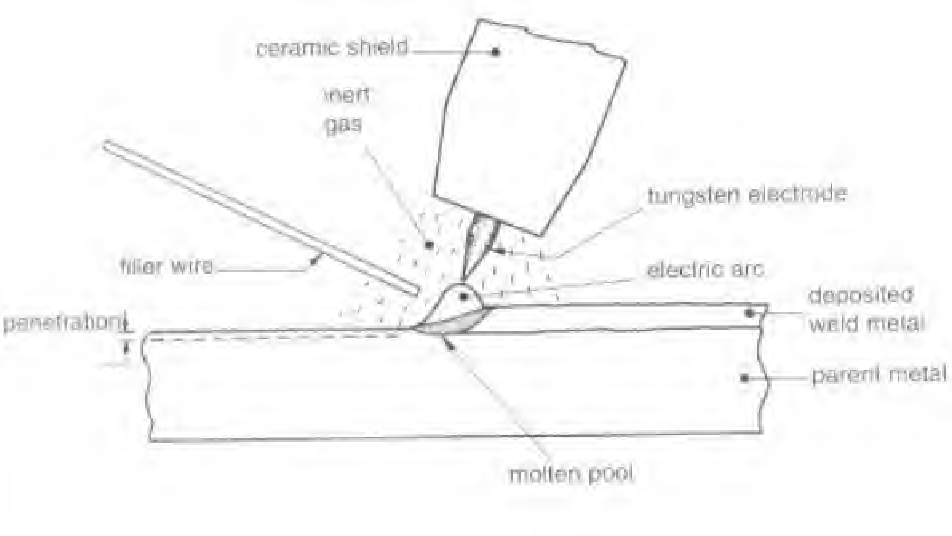
In this welding process an arc is formed between a tungsten electrode and the work to be welded, but unlike what happens in most processes the electrode does not melt. The only other processes in this category of 'non-consumable' arc welding are carbon-arc, its forerunner, and plasma-arc, which has replaced it in a few areas.

Where a weld needs filler addition this is not supplied by a consumable electrode, but instead as a separate addition of filler wire added exactly as in gas welding. The co-ordination of the arc and the filler addition requires considerable expertise, giving rise to TIG welding's reputation as the most difficult of the manual welding processes to master.

The arc is invariably protected by a completely inert gas shield, which prevents atmospheric contamination of the weld pool without any fluxing or chemical reaction.

Whilst TIG (tungsten inert gas) is the most common name for this process, it also is or has been known as argon welding, argon-arc, tungsten arc, TAGS (tungsten arc gas shielded) and GSTA (gas shielded tungsten arc) by the Americans.

TIG can be used to weld any metal but finds most use in high-quality sheet and pipe work in stainless steel and aluminium alloys. The process is slow compared to MMA or MIG but produces welds of the highest quality, which satisfy even the rigorous standards set by the aircraft, petro-chemical, nuclear and off-shore industries.



The TIG arc.

EQUIPMENT REQUIREMENTS

In the past TIG equipment tended to be an 'add-on' facility, extending the use of standard MMA welding transformers or generators. A TIG lead is substituted for the welding lead, provision is made for gas supply, and perhaps a contact switch (on-off) and HF (high frequency) arc-start unit.

Modern TIG welding sets have TIG as the prime facility, with MMA as a useful secondary function. All of the necessary mechanisms required to control the arc and gas flow are built in. Selection of a welder is guided by the thickness and type of metal to be welded. Thicker metals require a higher current capacity and/or better duty-cycle. Most metals can be welded with DC but the 'light' metals – aluminium, magnesium and their alloys – require AC.

DC TIG Sets

These are DC rectifiers with electrical characteristics identical to those of MMA machines. In common with other electrical equipment they have become ever more compact. A 200A unit is quite mobile, being lighter and no larger than a similarly rated oil-cooled transformer but having the advantage of being able to run all types of MMA electrodes.

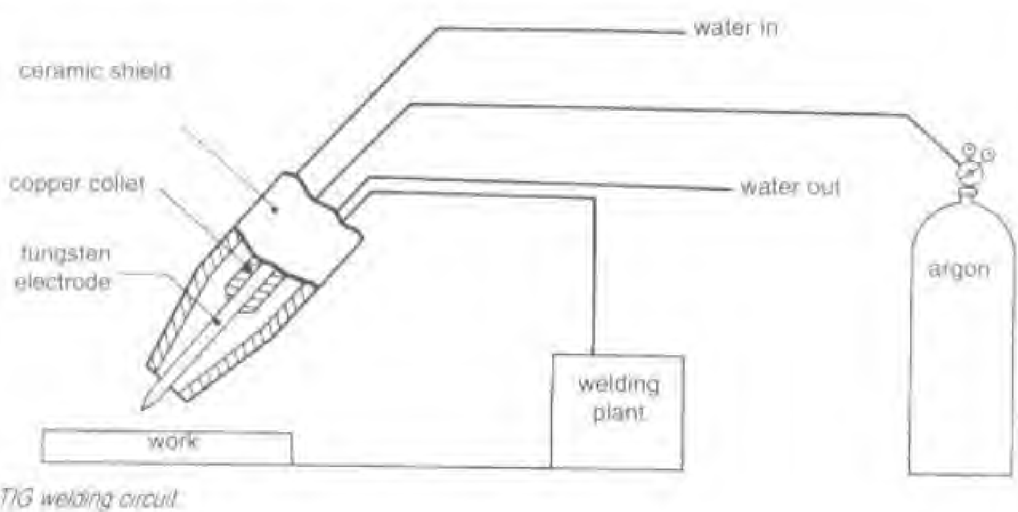
AC TIG Sets

TIG machines supplying AC as well as DC can be used for welding all metals.

An AC welding supply is essential for welding light alloys, which increases the cost of the machine significantly. In addition to the increased control circuitry required, it needs a bank of capacitors to control the inherent rectification that takes place in a tungsten/aluminium arc, and it must have an HF unit.

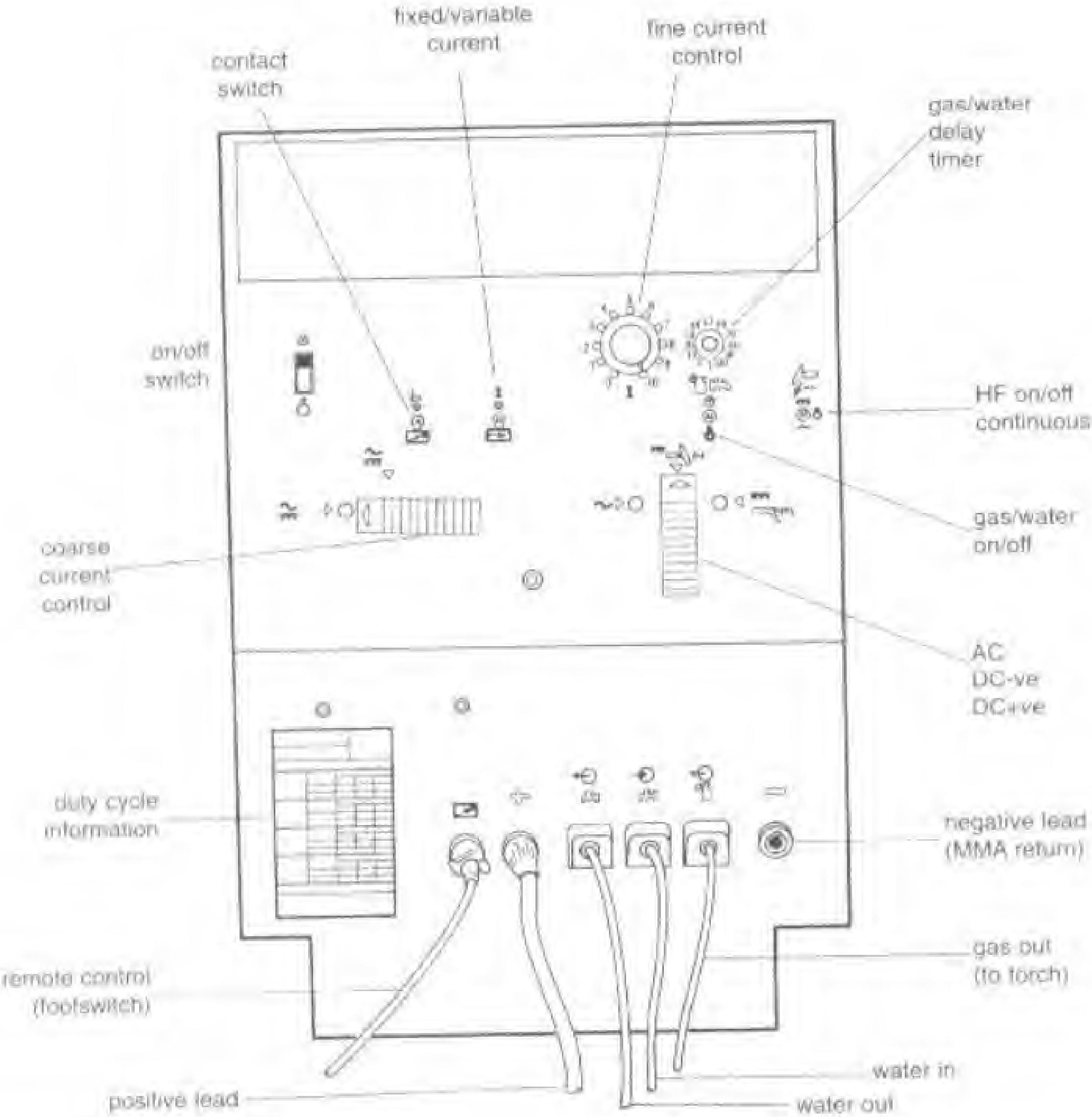
Features of TIG Welding Sets

An examination of the welding set will familiarize the operator with the control functions which can include the following:



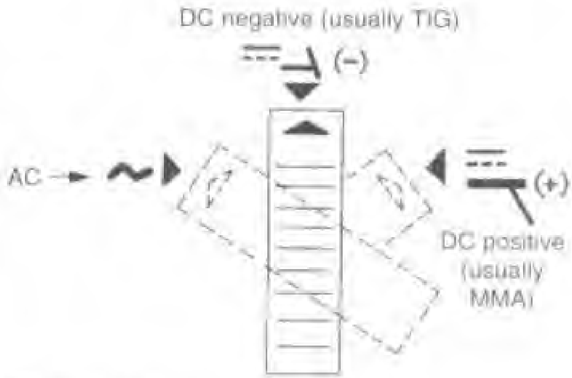
The TIG welding circuit

1. Polarity switch
2. Contact switch
3. Coarse current control
4. Fine current control
5. Variable current switch
6. Foot pedal
7. Internal/external switch
8. HF switch
9. Lift TIG or scratch start
10. Gas/water control switch
11. Gas/water timer
12. Flowmeter
13. Slope in/out switches
14. Economizer



Locating TIG function controls

The front panel of a typical TIG/MMA set.



The polarity switch

Polarity Switch

The polarity of the electrode on DC sets is controlled with the welding leads. The machine is preset for TIG welding with the electrode DC negative; for MMA welding the welding lead is connected to the positive terminal and the return made negative.

On AC/DC sets the switch has three positions: DC positive (the electrode), AC, and DC negative.

Contact Switch

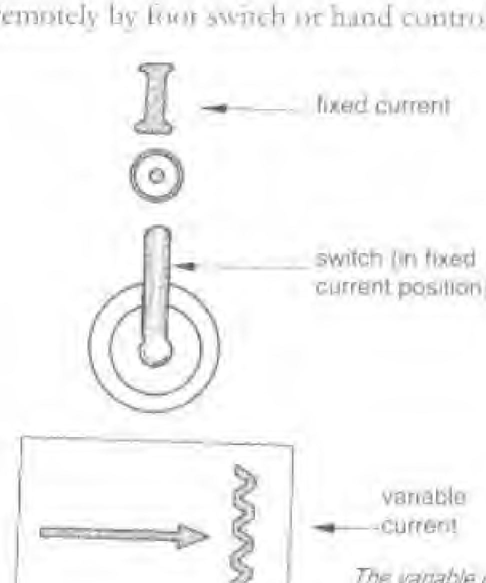
This switch is used to make the welding circuit live permanently, as is usual for MMA welding, or alternatively to enable this facility to be remote from the set. In the latter position contact is made either with a switch on the torch or with a foot pedal.

Current Conrol

Self-explanatory in function, the coarse current control switch offers one of a range of currents, and is found on larger machines.

A fine current control knob, usually identified as 'I' for current, is used for making final adjustment, but may be overridden by the foot pedal.

The welding current can be made either constant or variable, variation being effected remotely by foot switch or hand control.



The variable current switch

Foot Pedal

Solenoids controlling the contact, gas and water flow and HF are activated by a switch located on the torch, or by use of a foot pedal. Constantly relocating the foot pedal on large assembly work can be a nuisance but for bench work it offers a means of remote current control.

This facility can be used to control the heat as welding continues, but its intended function is to reduce the current gradually on completion of the weld so that weld crater shrinkage is less likely to result in cracking.

Internal/External Switch

In the internal position all control is on the machine itself. The external position is used in conjunction with remote control additions, which may be used either simply to control the current or, for example, to provide 'pulsed arc' welding.

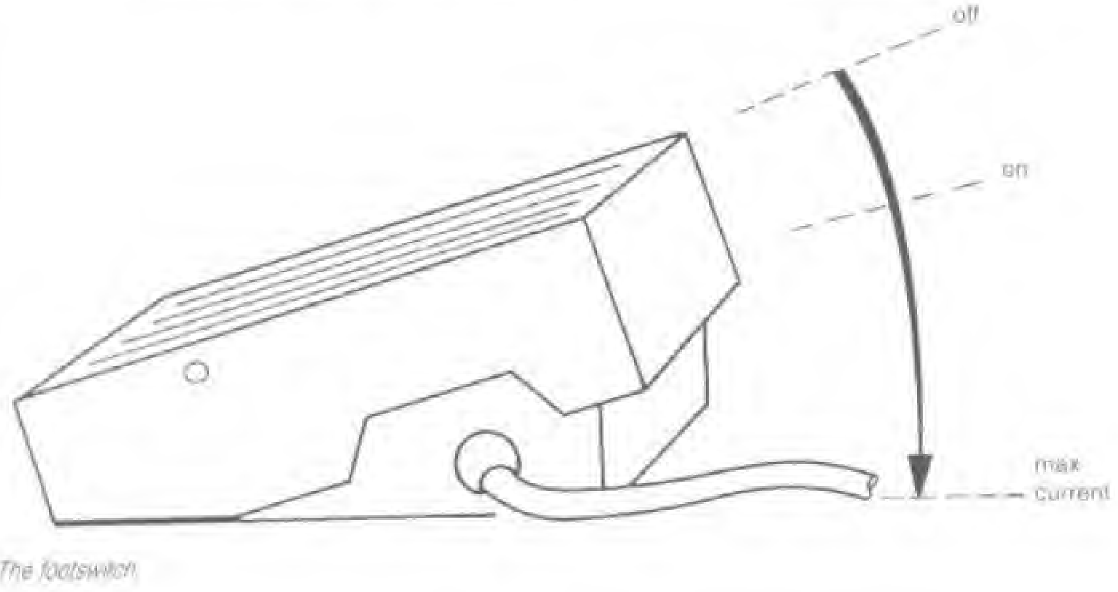
HF Switch

The welding circuit is superimposed with a high frequency, high voltage circuit, which at about 20,000V jumps the gap between the electrode end and the work. It does this with ease and looks like and has the same characteristics as 'lightning'. Welding current follows this 'electrified' path and an arc is established without having touched the tungsten on the work to close the circuit.

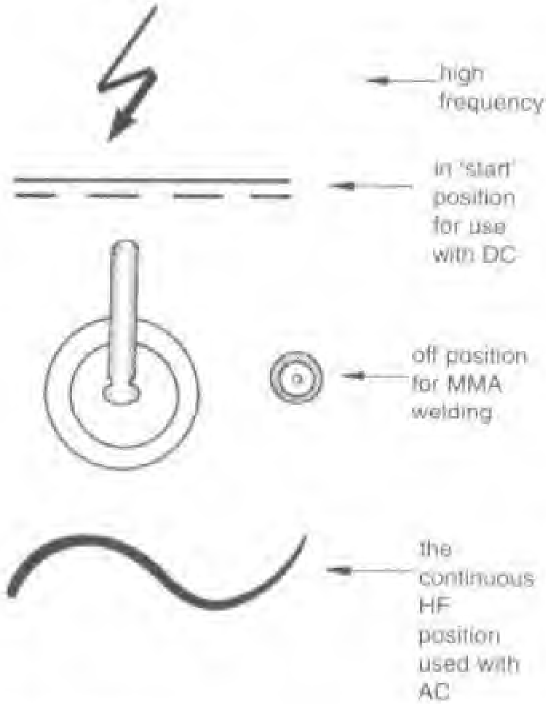
One of the frustrations of TIG welding that is quickly discovered is that if the tip touches the work it gets contaminated, making the arc difficult to use and weld quality very poor. If the electrode is touched down it must be removed, ground back to unaffected metal and a restart made.

HF is only needed to initiate a DC arc because once it has been established current will continue to flow. When AC is used it will cut out unless the HF is used continuously to keep re-establishing the arc as the AC sine wave goes through zero.

On AC/DC sets the HF switch offers three positions: start, continuous and off. It should not be used unless needed because it



The footswitch



The HF switch

causes interference to radio and TV signals, and at its high voltage tends to 'track' through angle grinder leads, welding wires, from one machine to another unless care is taken to isolate the equipment.

Lift TIG or Scratch Start

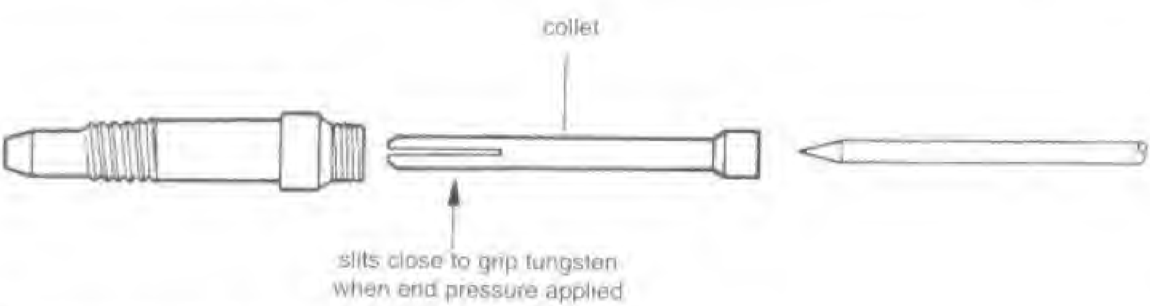
In recent years lift TIG has provided a viable alternative to HF and without its problems, but is only useful for arc initiation on DC.

To strike, the tungsten is shorted on the work, the torch switch is pressed on and the electrode is lifted up to create an arc. The position of striking is very precise and stray HF/arcing does not mark the metal surface outside the joint area. It is successful because the current flowing initially is very low, rising over about 2 seconds to the machine's setting; and it is claimed to produce X-ray quality welds that do not suffer from tungsten inclusions.

Gas and Water Control

The gas/water control switch is unnecessary for MMA but is switched on for TIG welding. Forgetting to do so results in:

1. No gas flow. The tungsten immediately oxidizes and becomes unusable without remedial grinding, and the pool/crater oxidizes and must be ground away to sound metal before welding is recommenced.
2. No water flow. The welder either will not work at all because it is controlled by a solenoid relying on water flow, or it will work for a short period and then blow a water immersed fuse, which must be located and replaced before welding can continue.



The tungsten electrode gripping mechanism

The gas and water timer enables the gas and water to flow for a preset length of time after the arc has been extinguished. This allows the weld pool to cool in a continuing supply of inert gas, and water to continue to flow through the torch assembly, cooling it quickly.

Flowmeter

A flowmeter will measure the amount of gas flowing through the line rather than the pressure it is at. The units will be volume and time, in the past cubic feet/hour but now litres/min; pressure was measured in lb/sq. in (psi) in the past but now in bar. The actual flow is quite critical and will vary with the shroud diameter and the gas retention/loss nature of the joint. It is set with the gas, welder and torch all turned on, by positioning a bobbin at the desired height in a glass flask in the line.

Slope In/Out Settings

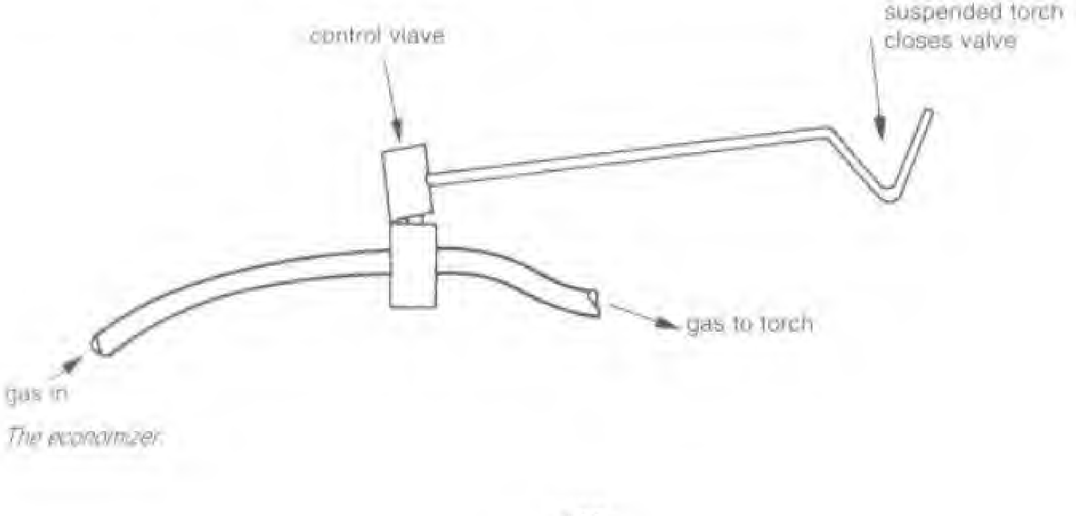
Typically in arc welding the arc reaches full intensity almost instantly, and is extinguished at the same rate. 'Slope in' enables the current to build up to the level set over a predetermined period, and similarly the 'slope out' can be used to cause the arc to fade gradually, allowing the crater to fill in and reducing the prospect of crater cracking. These machine settings reduce the attractiveness of foot pedal control.

Economizer

When the economizer is used, the gas supply is not controlled with solenoids/timers but is fed directly to the torch, interrupted only by the economizer. This in-line valve is closed by suspending the torch on it, and opens as the torch is picked up to be reused. The length of time that gas flows after welding ceases is now controlled manually by the operator, who may find this control useful for bench work but not for large assembly work.

Assembling the Equipment

Assuming the welder has an adequate power supply, the torch assembly can be fitted to the welder. The fittings usually have helpful symbols or are self-evident, with connections for the welding lead and gas supply and perhaps water in/out. Gas must also be supplied to the welder and water as necessary.



The economizer.

EQUIPMENT MAINTENANCE

The equipment requires practically no maintenance, the tungsten itself being the ongoing exception. Each time it touches the weld pool, or filler wire in transit to the pool touches it, the contaminated end must be ground back to sound metal. The skill and experience of the operator, and the ease with which he can approach the work, will determine how frequently this happens.

When the torch used is water cooled, a constant water supply must be ensured and is provided in one of the following ways. The supply can be direct from the mains, and flow away to waste, or the supply can be self-contained and recycled from a water tank located at the rear of the machine. This eliminates the plumbing requirement and makes the machine more portable.

Occasionally a broken ceramic gas shroud needs replacing and eventually the torch hose's polythene sheathing as well. Hoses themselves age-harden and lose their flexibility, which makes the torch more difficult to manipulate.

PREPARING THE WORK

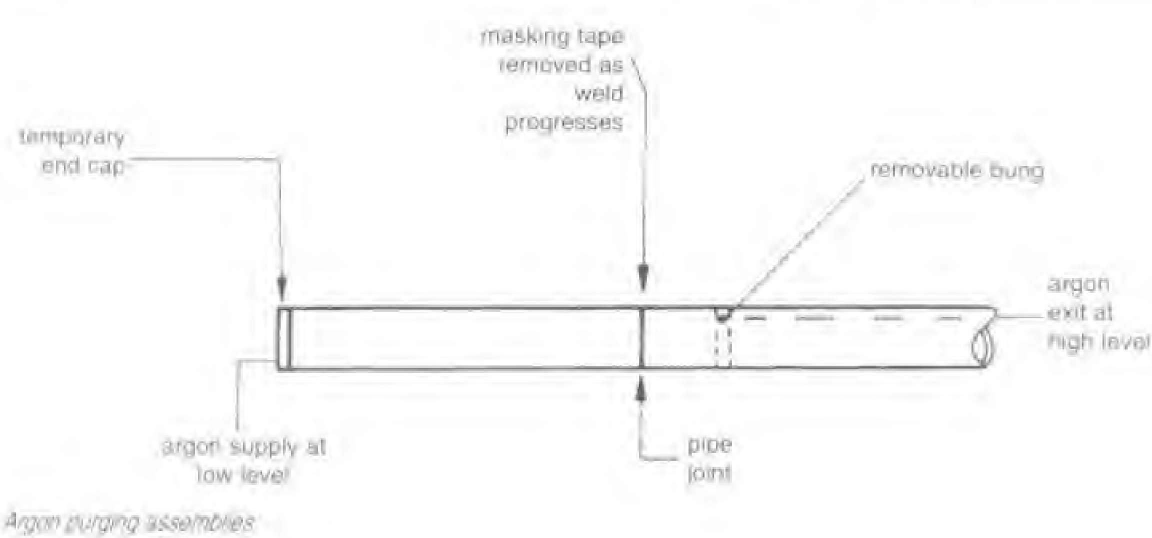
Cleaning

The advantages of the TIG process can only manifest themselves if the metal is very clean. All oxide must be mechanically removed by grinding or sanding to leave a bright surface. This is followed by degreasing in a suitable solvent, and from this point onwards the metal must be handled with clean cotton gloves.

Once clean, fillets and lower quality butts can be kept that way adequately with the gas supplied from the torch, but this is of course only to one side of the joint. A secondary supply of gas can be applied to the underside of butt joints where quality demands it.

Pipe work can be kept clean by blocking off the pipe a little to each side of the joint, and then purging this temporary chamber with gas for some time before welding commences. Masking tape wound around the joint ensures no loss of gas and is removed as welding progresses.

The underbead of butts in plate or sheet



Argon purging assemblies

can be kept clean by using either a backing bar or strip. Backing bars are copper strips with a groove in the surface that can be used to mould the underbead. Gas is fed into the bar and exits into the groove via small holes along the bar's length.

Backing strips are strips of the material being welded, which are tacked to the underside of the joint. The butt can then be made with less regard for control of penetration or argon protection, but the strip does become an integral part of the joint, which may be undesirable. Backing strips can equally well be used in pipe butts, and with butts made using the MIG or MMA processes.

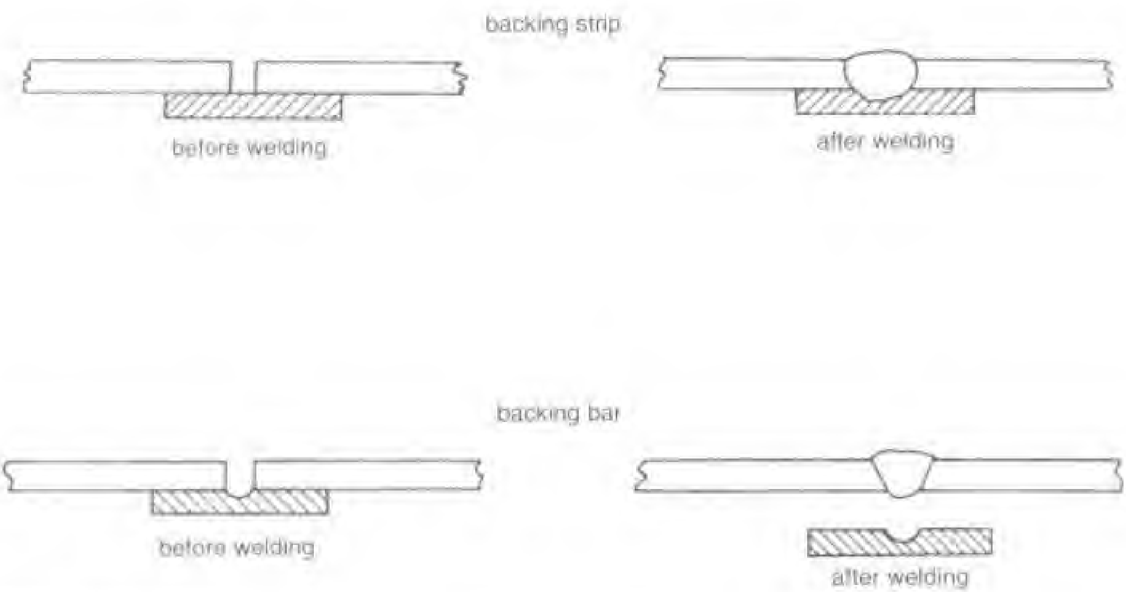
Edge Preparation

The TIG arc penetrates very well so square edges with no gap can be used up to 1.5mm thicknesses; up to 2.0mm the gaps never need to be more than 1.0mm. On thicknesses above 2.0mm 60-degree Vs are necessary.

PREPARING TO WELD

The sequence of events leading up to striking an arc is:

1. Prepare metal as above.
2. Select type and size of filler wire.
3. Select type and size of electrode.
4. Select gas shroud.
5. Don protective clothing and gloves.
6. Don head screen (essential as both hands must be free to hold the torch and filler wire).
7. Select polarity.
8. Set current on welder.
9. Select lift TIG or HF position.
10. Check contactor and variable current



Backing bars and strips.

selector or slope in/out

11. Set gas delay.
12. Ensure water supply is ready.
13. Turn gas on and regulate flow.

Filler Wire

A wide range of wires is available, designed to match, or more often exceed the quality of the parent metal. The majority of these are either stainless steel or an aluminium alloy.

British Standard BS 2901 Part 1 was superseded in 1995 by EN 440, which covers carbon steel wires for TIG, MIG and gas welding. Part 2 (for stainless steels), part 3 (for copper alloys) and part 4 (for aluminium alloys) continue to be the standard applied but will eventually also give way to a European standard.

The type of wire is stamped on flattened portions towards each end so that its category can be identified when new or partially used. A 316S92, for example, is appropriate for type 316 stainless steels.

In the absence of a suitable wire through poor stock control, or if the precise alloy type is unknown or no matching wire is commercially available, it is common practice to cut narrow slices from the same sheet and use these as filler.

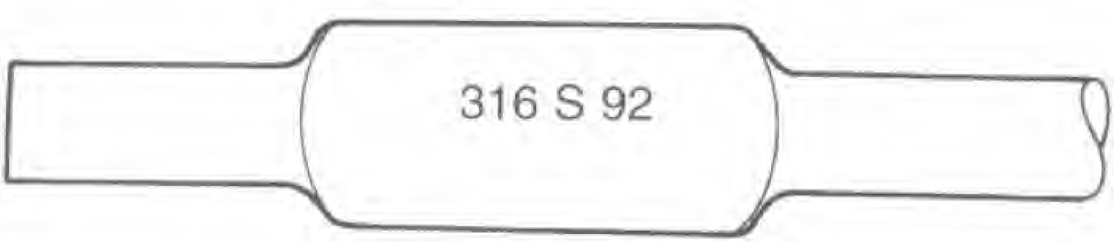
With regard to size, the same considerations apply as for gas welding, that is, the largest diameter possible consistent with smooth and easy melting should be used. It will be approximately equal to the metal thickness up to sheets of 3.0mm. Large TIG weld beads have a weak crystalline structure so it is unnecessary to have filler wires larger than 3.0mm.

The Tungsten Electrode

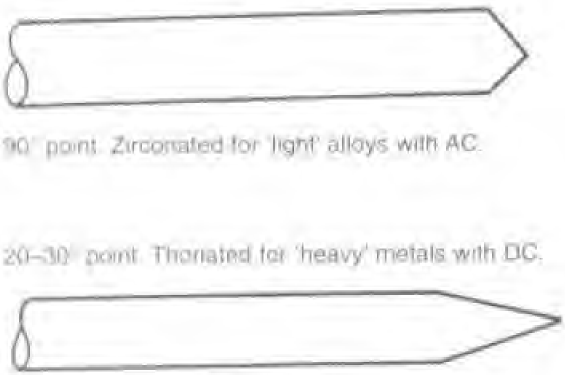
Making the tungsten electrode DC negative, and perhaps having the torch water cooled, help prevent the electrode melting, but its success as a non-consumable electrode is owed mainly to its very high melting point of 3400°C.

Some alloying additions are made to improve arc striking and stability. Thoriated electrodes contain 2 per cent thorium oxide and are best for DC welding, whilst zirconiated ones are most suitable for AC welding of aluminium.

When using DC power the electrode is ground to a 30-degree point, which concentrates and stabilizes the arc. The electrode gets hotter on AC and if a sharply pointed end is used it would melt a little and become rounded, so the end is simply ground to 90 degrees.



TIG wire identification



Preparing tungsten electrode ends.

Maximum current density should be aimed for, with the smallest electrode that can be used without it melting. If the diameter is too large the arc wanders around the electrode end without focus and is difficult to use.

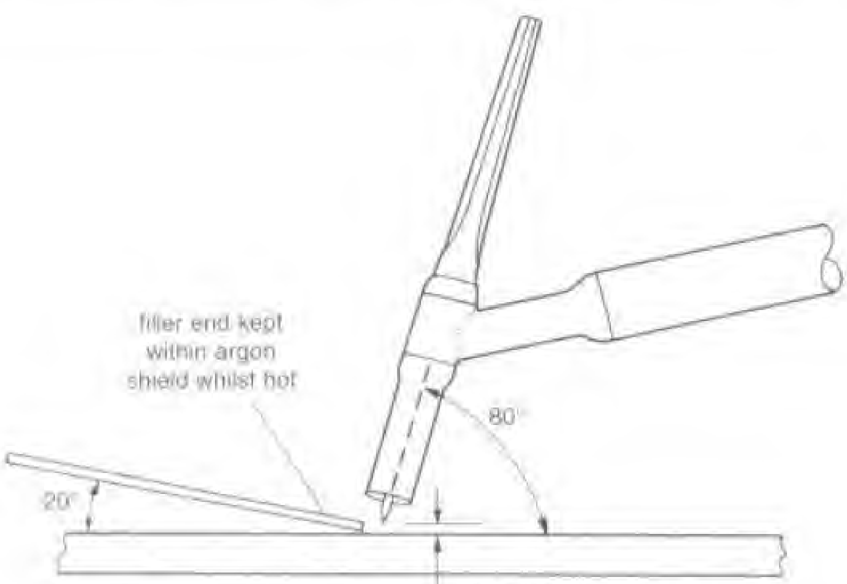
Gas Shroud

The diameter of the ceramic shroud is varied to provide enough gas at a flow rate high enough to displace the air. Economy dictates that the smallest possible is used with the lowest flow rate that adequately protects the weld pool.

Gas protection can be improved by using a gas lens which is located inside the shroud giving the gas directionality and much cleaner welds for a given gas consumption.

MAKING A WELD BEAD USING DC

The welder is set on about 80A to suit either a piece of cleaned mild or stainless steel of approximately 150mm × 100mm × 1.5mm. The torch is held at 80 degrees, pointing in the direction of travel, with the pointed end of the tungsten about 2.5mm above the sheet surface. The filler wire is placed on the sheet surface about 10mm away in readiness to add it to the pool and where it can be seen in the light of the arc.



TIG torch angles.

The torch switch or the foot switch are located in readiness to strike the arc; the raised headscreen is flicked forward to cover the face, and the arc is initiated.

The weld pool forms over a few seconds (not instantly but quicker than with gas) and is allowed to grow to the size desired. Filler wire is fed into the pool either directly or by sliding it along the surface, but definitely avoiding the electrode!

Progress is made much as it is in gas welding, by repeating the following cycle as finely and smoothly as possible:

1. Melt pool.
2. Allow it to grow.
3. Add filler to give required build-up.
4. Withdraw filler, but not out of the gas shield.
5. Move forward.
6. Allow pool to grow and so on.

TIG welding can require all four limbs!

At first this sequence is likely to be executed in a somewhat stilted, exaggerated way but with practice the distinction between each of the above stages becomes less obvious. The sequence may seem quite elementary but the experience of co-ordinating each hand whilst viewing a small bright light through a dark filter glass requires much skill. The job might be further complicated by having to maintain the position of a current control foot switch, and if the work were on a turntable (controlled by the other foot) the movement of all four limbs and the head would have to be synchronized.

To be able to address the work in a comfortable, controlled way is of paramount importance, but the following variables also play a part.

Factors Affecting the Quality of Work

Welding Current

High currents are difficult to control and force fast welding speeds, which is fine in automated situations but for manual work is too demanding.

Low settings lack fusion and depth of penetration and make it difficult to add filler smoothly. Reducing the welding speed will offset this to some extent.

Welding Speed

Clearly, welding current and speed are correlated, with higher speeds demanding a higher current, and vice versa. Providing the weld

can be kept under control, fast manual speeds are desirable because these produce the least distortion.

Arc Length

This is very susceptible to variation as the weld progresses, but the variation can be reduced by using the 'pencil' grip. Holding the torch from underneath, perhaps with the edge of the gloved hand sliding along the sheet surface, is much more controllable than the 'power' grip (hand above the torch) used in gas welding.

Long arcs cause the arc to spread widely, with wide, shallow melting because of the drop in current. Since the shroud/work distance also increases this may allow ingress of air and subsequent contamination of the weld. The arc should be as short as possible, but when it is too short contamination of the electrode is likely, through touching down on the work or misdirecting the wire into the narrow arc gap.

Restarting the Bead

Some types of stainless steel in particular may oxidize in the crater enough to necessitate grinding. Otherwise simply ensure that the crater surface is fully melting before adding filler and progressing.

Finishing the Weld Bead

At the end of the bead the crater is filled in to prevent weakness/cracking at this point. This is done by topping up with filler wire and is easier if the current is made to decay gradually, either with slope out or with the foot switch.

The best TIG torch grip for bench work.

The arc is extinguished by switching it off not by lifting the torch up, and the torch should remain stationary long enough for the post-weld gas flow to protect the crater during cooling.

MAKING A BEAD USING AC

Since magnesium alloys are not welded very often it is likely to be aluminium that demands AC. The differences between this and using DC are as follows.

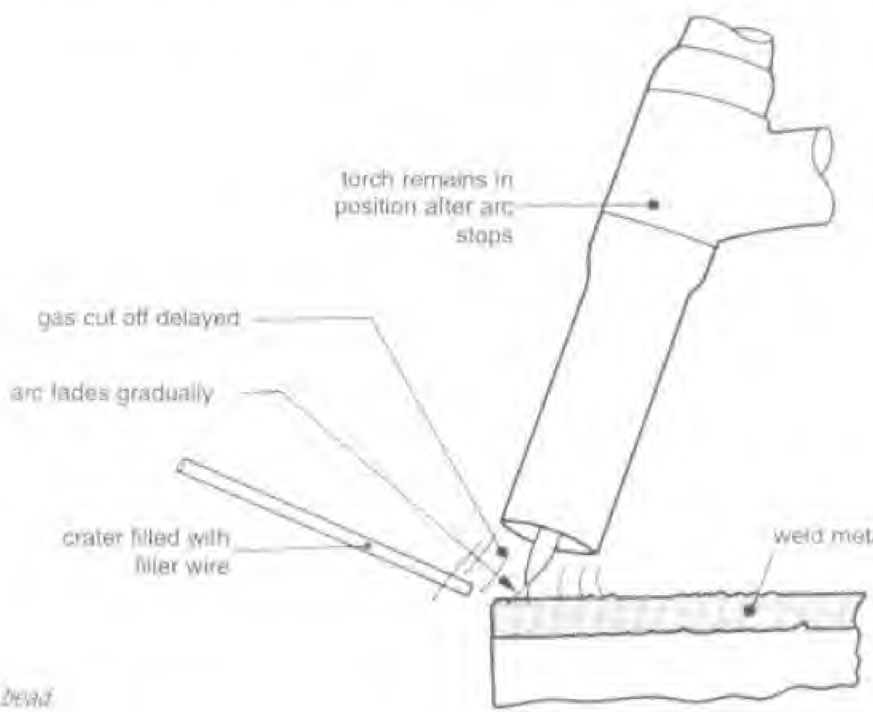
The HF is set to 'continuous' and a zirconiated electrode is inserted. The arc is less clearly defined than when using DC, is quite noisy and takes longer to create a weld pool. The filler wire's melting point of about 650°C is much lower than steel's, and it must therefore be added quite quickly and deftly to prevent it from melting back into a ball and blowing away before it reaches the pool.

Aluminium gets very hot some distance away from the weld because of its high thermal conductivity, the heat travelling both through the metal and up the filler wire. Burns are also possible from the continuous HF, particularly if the wire makes contact with the electrode.

SHUTTING DOWN PROCEDURE

Shutting down is simply a matter of:

1. Turning off the welding set at the isolator.
2. Turning off the gas cylinder.
3. Unwinding the gas regulator adjustment knob.
4. Closing the water tap if on mains supply.
5. Returning usable lengths of filler wire



Finishing a TIG bead

back to the packet or, if uncertain about their identity, scrapping them.

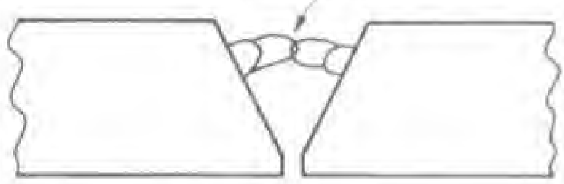
MAKING TIG WELDED JOINTS

Most of the principles of producing good TIG welds have already been established, and it should now simply be a matter of applying them and (a) following a joint line and (b) supplying the right amount of heat/filler to produce a sound bead with a good profile.

Tacking

Tacks are made easily enough but the metal may distort either as it is heating or as a result of tacking. The amount of restraint required to prevent this happening will be learned with experience.

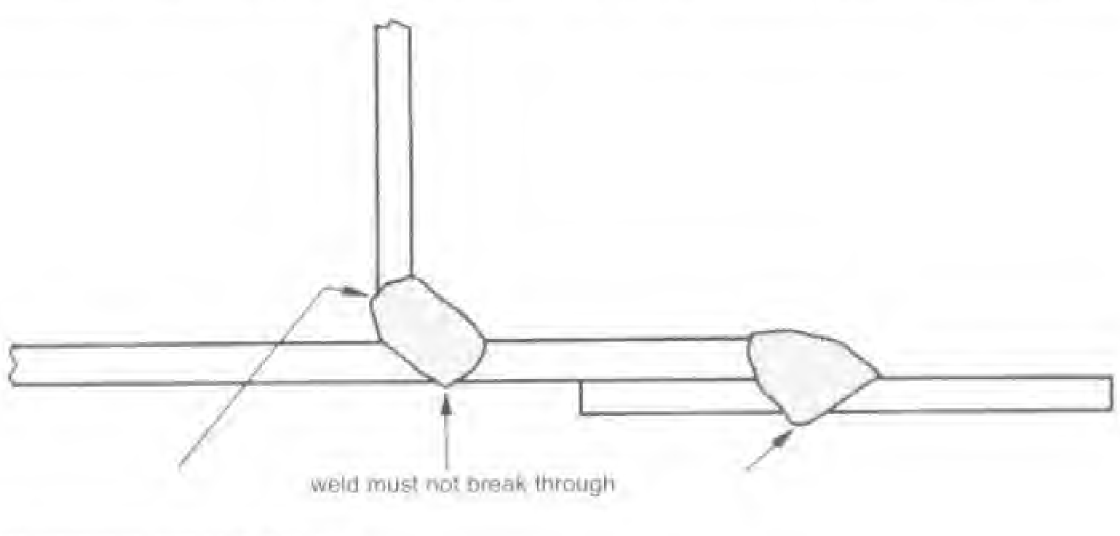
The care over cleanliness and fusion when welding is also required during tacking since the tacks are to become fused into the weld. Alternatively, tacks can be removed from the joint as they are approached and this is accomplished most easily on V preps by using 'bridge tacks'. As the name implies, these are built up from each side until they form a bridge across the upper part of the V, thus aligning the plate while still being easy to remove.



The bridge tack.

Fillets

In common with other welding processes the weld pool should be observed to fuse well into the corner at the leading edge, and build up in the desired profile at the freezing



Over-penetration in fillet and lap joints.

trailing edge. Some regulation of the current/speed may be necessary to prevent the weld breaking through the unwelded side of the joint.

The minimum requirement of any fusion weld is that it should be fused to all of the parent metal it is in contact with, but the balance between this and not breaking through in thinner TIG T-fillets and lap joints can be quite tricky.

Butts

The principle and technique of welding butt joints are to a large extent the same as when gas welding, with the difference simply being the heat source. After experience of gas welding, the pool will seem to appear quickly and the arc to penetrate very well. Establishing a weld pool key-hole is not necessary, and gaps need only be about 0.75 × the metal thickness to melt through easily. A slight 'sinking' of the pool indicates that it is penetrating, filler is added to regain control and build the profile up, the torch is moved forward and the cycle repeated.

The merits of using backing gas, or a backing bar or strip need consideration; their use is dictated by the end purpose of the joint.

The surface of a stainless steel weld bead is never perfectly bright, and on multi-run welds inter-run cleaning with a small grinder may be necessary if the surface is scummy or oxidized.

7 WELDING OTHER METALS

The welding instructions in this book are based on mild steel, since most welding is done with this material. This chapter considers the weldability and techniques required for other metals.

COPPER

Its high thermal conductivity makes arc welding copper very difficult, but TIG is successful on thinner sheet, using either strips cut off the side or proprietary filler wire. It can be gas welded but takes a long time to form a weld pool, by which time much of the metal is hot so that welding then has to be done very quickly.

The non-fusion methods of soldering or brazing copper are easier because the heat requirement is much less.

ALUMINIUM

In general the problems with welding aluminium are its low melting point and high thermal conductivity, which tend to result in slow formation of a weld pool, or lack of fusion at the start, followed by high welding speeds because the metal has become very hot in getting started.

Aluminium oxide is very refractory and requires a strong flux and good cleaning before and after gas and MMA welding.

Oxy-Acetylene Welding

Having a high conductivity like copper, aluminium is also slow to heat and fast to weld. The correct wire and flux are needed with the flux mixed to a paste and painted on for improved control. The metal melts without any colour change, and close attention must be paid to the formation of the weld pool if total collapse of the metal is to be avoided.

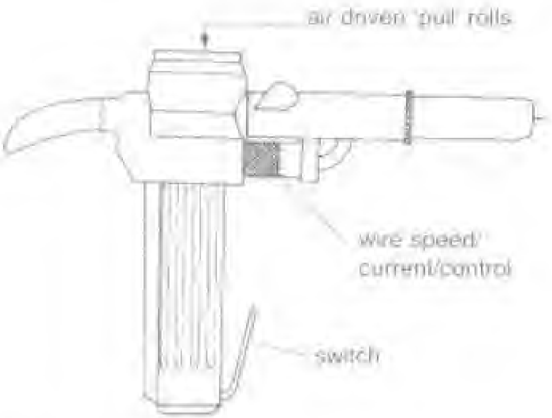
MMA Welding

Aluminium electrodes run on DC only and are very difficult to control evenly along the joint length.

MIG Welding

With its balance of speed and quality this is now the prevalent method for general aluminium fabrication. A 'hard' alloy wire from group 5 is needed which will push through the liner evenly and ensure a stable arc. Alternative wire feed methods are 'spool on gun' (self-explanatory) and push-pull systems. The latter has rolls within the torch head which pull the wire and keep it taut,

ensuring a smooth feed when using a soft aluminium wire.



The 'push-pull' gun.

TIG Welding

TIG welding is a little slow, but this is offset by guaranteed quality and access to a wider choice of filler wires to match the particular alloy. MIG and TIG welding both need pure argon shielding gas.

STAINLESS STEELS

There are many alloys which are collectively known as stainless steel and they fall into one of three groups:

1. Martensitic
2. Ferritic
3. Austenitic

A MIG bead (left) and a TIG bead (right) on the surface of aluminium sheet.

The first two are not widely used in situations where they have to be welded and hence not often encountered in repair work. If welded, some deterioration in mechanical properties or heat treatment is necessary. Austenitic steels are used for fabrication and are readily weldable but compared to mild steel closer attention will need to be paid to:

1. Cleanliness of material prior to welding
2. Keeping the metal free of oxidation during and immediately after welding
3. Selection of consumables to suit the parent metal
4. Heat input
5. Distortion control

Cleaning

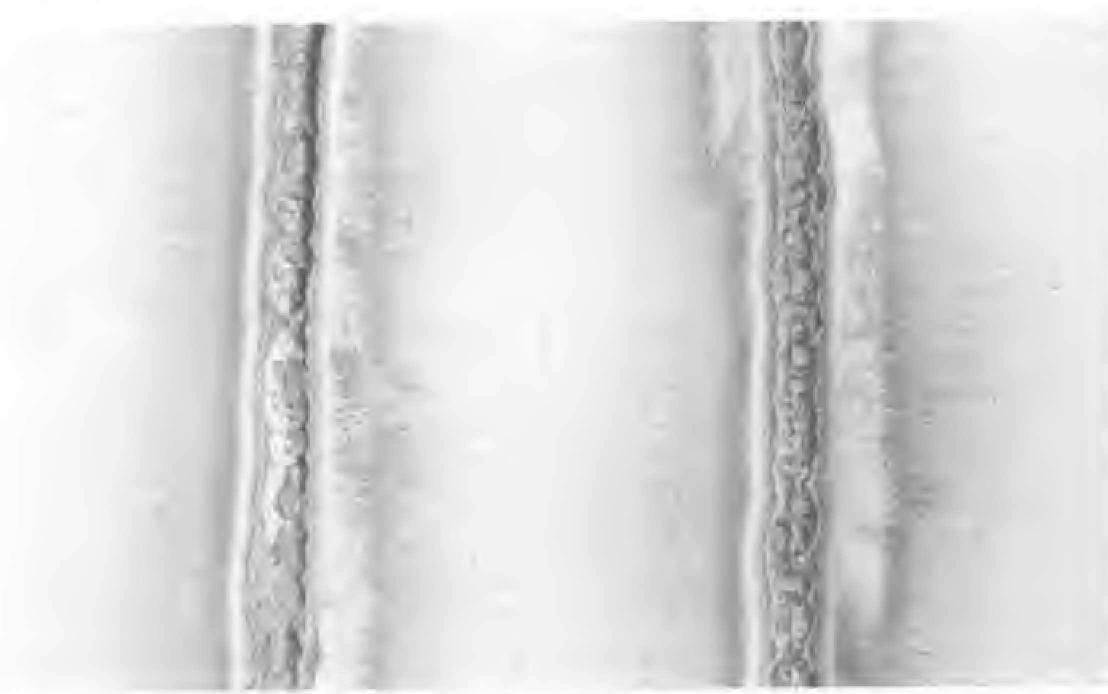
The joint area is cleaned mechanically, ensuring that no grinding grit is transferred to the surface, and chemically with a suitable solvent. Ensure that all solvent has evaporated before welding and take care not to breathe in vapour or vapours which produce phosgene when exposed to an arc.

Oxides and scum are very refractory and aggravate weld pool control, so they should be removed by grinding between runs.

Oxidation is prevented with the flux in gas and MMA welding, and with the shielding gas in MIG and TIG welding. Quality TIG welds also require argon purging of the underside of the joint.

The Consumables

These must match the parent metal as nearly as possible. It is quite possible to produce a weld that is visually good, passes X-ray



Underbeads of TIG welded butts in stainless steel with argon protection (left) and without protection (right).

examination and so on, but fails critically and prematurely when put into service because the weld metal composition and hence its physical properties are wrong.

Heat Input

This will be kept as low as possible in order to reduce crystalline change and growth in the heat affected zone. Welding must be done as quickly/cooly as possible, and the work may need to be allowed to cool down between multi-runs.

Expansion/Contraction

This property is put to good use in many areas of engineering, but in welding causes much frustration. Two notable characteristics of stainless steel are its high coefficient of expansion and its low coefficient of thermal conductivity. The effect of this in welding practice is that the heat tends to stay where it is applied and the metal expands dramatically at this point.

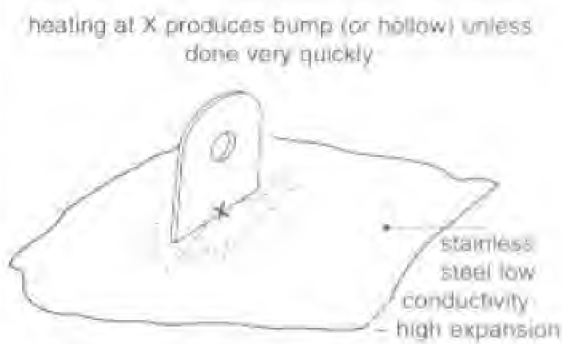
Since stainless steel distorts twice as readily as mild steel greater attention will need to be paid to:

1. Tacking frequency
2. Heat input
3. Weld sequence

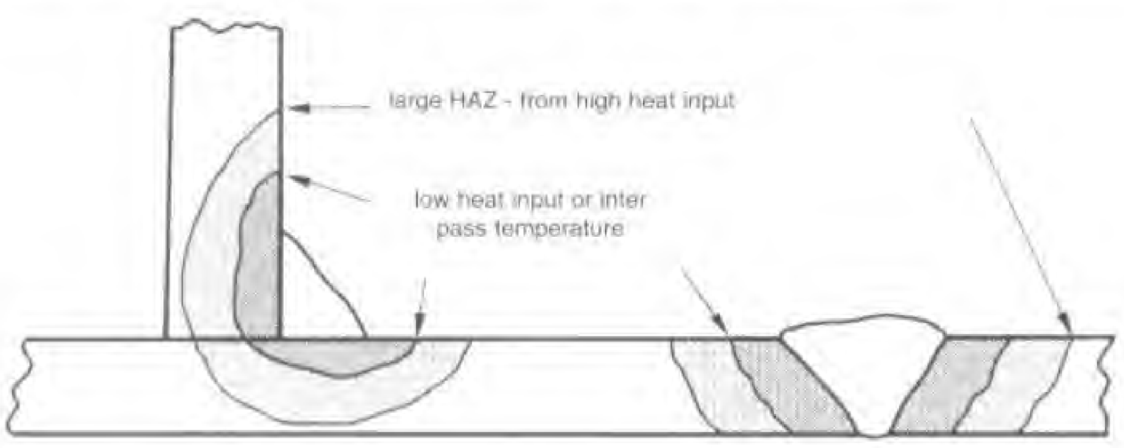
Choosing the Welding Process

Oxy-Acetylene

A suitable filler and flux for stainless steel are required, and a fair degree of skill. This process has now completely given way to the TIG process.



Spot heating 'bump' in stainless steel



Heat input/HAZ size relationship.

MMA

There is a wide choice of electrodes available to suit various grades of steel, with one of the following types of coating:

1. Basic coated. These are basic carbonate or low hydrogen coatings, which are best for positional work but need a DC supply.
2. Rutile coated. These run on AC as well as DC but are best in the flat position.

The specific rod chosen will need to match or have a higher alloy content than the metal being welded; for example, a 19.9 (19 per cent Cr, 9 per cent Ni) electrode would be selected for a type 347 (18.8) stainless steel.

Making MMA welds in stainless steel is generally quite straightforward, with good results and good slag detachability but the following points should be noted:

1. The arc must be kept as short as possible to prevent loss of alloying elements.
2. V preps, gaps and so on should be wider than for mild steel because the metal is more viscous (and thus more controllable).
3. Electrodes must be completely dry, and after opening be kept in a heated oven or heated quiver until immediately prior to use.
4. The slag entrapment inherent in closed joints like fillets may promote premature corrosion and therefore may make this method unacceptable.

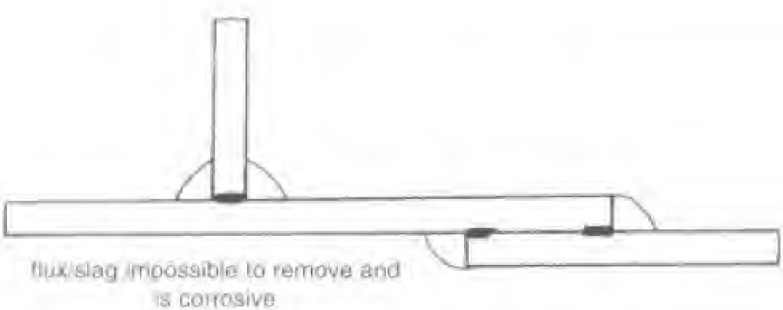
MIG/MAG

The advantages of high assembly and welding speeds still apply but this process is not widely used where welding standards are stringent because:

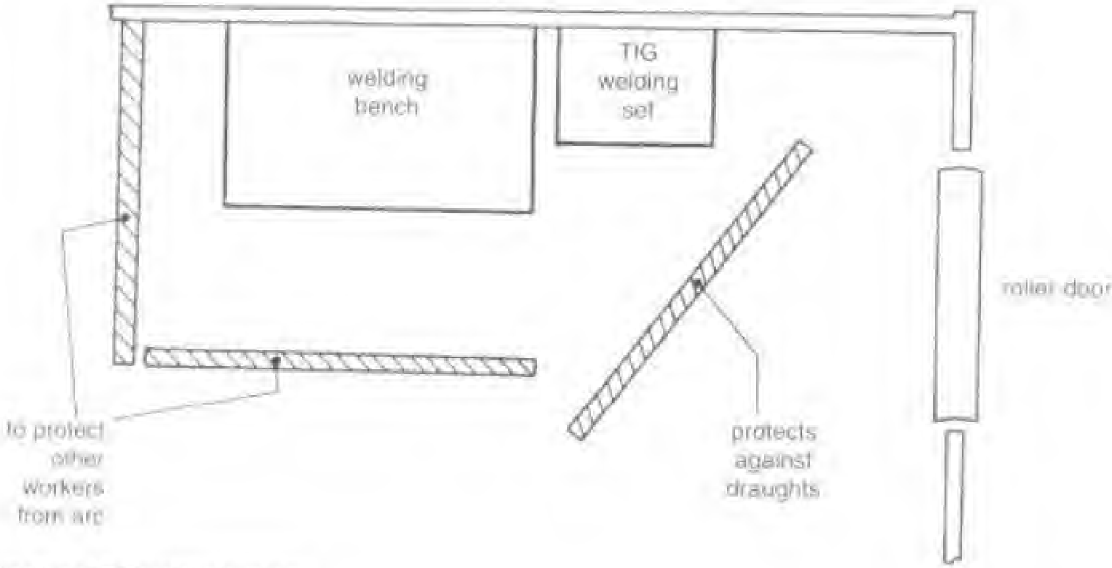
1. The weld surface tends to oxidize and look poorer than with either TIG or MMA welding.
2. The process is very susceptible to lack of fusion.
3. Control of weld metal composition is more difficult than with TIG (no transfer of wire through the arc) or MMA (fluxing of weld pool).

TIG

This is most widely used and accepted where high quality is required. It offers good control of fusion/penetration, particularly in roots, but is slow, prone to distortion and demands the most skill of all the methods. Argon is used as the shielding gas, and protection against weather conditions may be needed on site to keep this in place. In the UK, MIG and TIG wires are selected from BS 2901:Part 2.



Slag and flux penetration in lap and fillet joints



Site plan of TIG welding screens

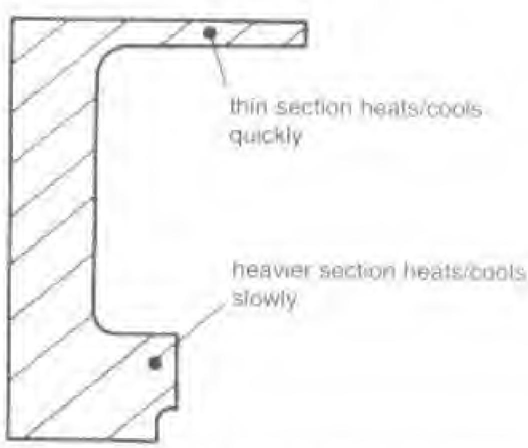
CAST-IRON

Cast-iron components are cast directly into their finished shape, and so the ability to fabricate or weld it was never part of the design process. Welding is therefore always to repair or restore either functional or ornamental qualities.

The material is most useful in making items of complex shape and varying thicknesses, but these are likely to heat/cool at very different rates. Combined with its low ductility, this makes cast-iron very susceptible to cracking unless great care is taken to both heat and cool the metal evenly. The problem is aggravated by the high carbon content, which makes the metal even more brittle if cooled quickly.

Welding Procedure

1. Strip down to a 'single' component if practical/possible.
2. If cracked, drill holes at each end to prevent the cracks spreading.
3. Grind V to the base of the crack; it may be easier to prepare if broken in two.
4. Select the welding method.
5. Decide if and how to preheat.
6. Preheat.
7. Weld.
8. Cool – very slowly!

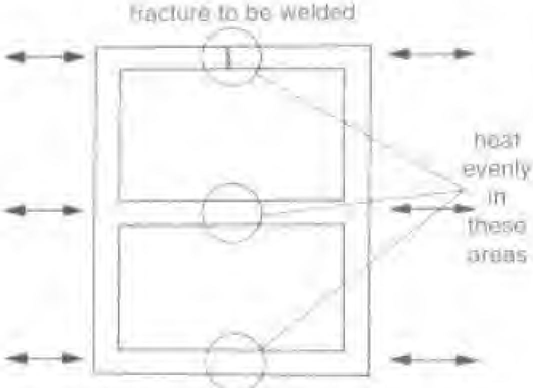


Heating/cooling rates affected by variable thicknesses

Preheating

This is unnecessary for small simple castings, but more complex ones require one of the following preheating options:

1. None – if cold arc welding is used.
2. Local – merely to retard the cooling rate and prevent it hardening.
3. Local – at one or several points away from the joint area to cause the casting to shrink uniformly after welding.
4. Full – to reduce local hardening and equalize expansion/contraction throughout casting.



Local preheating

Gas Fusion Welding

A neutral flame, cast-iron filler stick and cast-iron flux are needed. The metal melts easily and is very fluid, making control at starts/ends a little difficult. The filler is gently coaxed into the pool without pushing in the oxides, which glisten on the surface. A sluggish, scummy pool indicates that more flux is needed but excessive use should be avoided. Gas welds have perfect colour and strength match but are restricted to flat welding of relatively small castings and often need a high preheat.

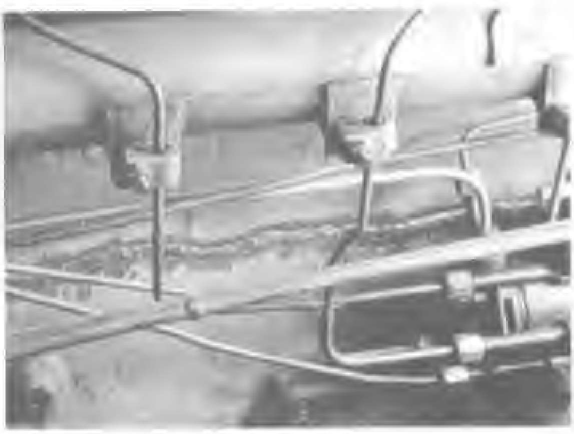
Gas Braze Welding

A manganese brass wire and brazing flux are used with a slightly oxidizing flame. Trickier than mild steel; the joint surface of cast iron is prone to oxidizing and subsequent lack of wetting; when this happens, the metal must be allowed to cool and the surface be recleaned before welding can be continued.

Arc Welding

MMA

Cold arc welding is the term used for making very short beads (20–40mm long) and allowing them to cool to hand hot before welding in that area recommences. No preheat is used, which makes it suitable for large castings, or ones difficult to strip down.



A 'frost crack' in a cast-iron tractor engine block repaired by 'cold arc' welding.

A 55 per cent Ni/45 per cent Fe alloy is the most common but higher nickel content rods produce more ductile welds. These can also be used for 'hot' welding in the conventional way providing a good preheat is used.

Some expense can be saved with the

buttering technique. A layer of high nickel weld metal is layered on each surface of the joint, and the centre filled with mild steel electrodes.

MIG

The expense of a spool of wire may be warranted for the welding of large castings.

TIG

Good quality welds are easily made this way but fast cooling rates cause cracking unless a good preheat is used.

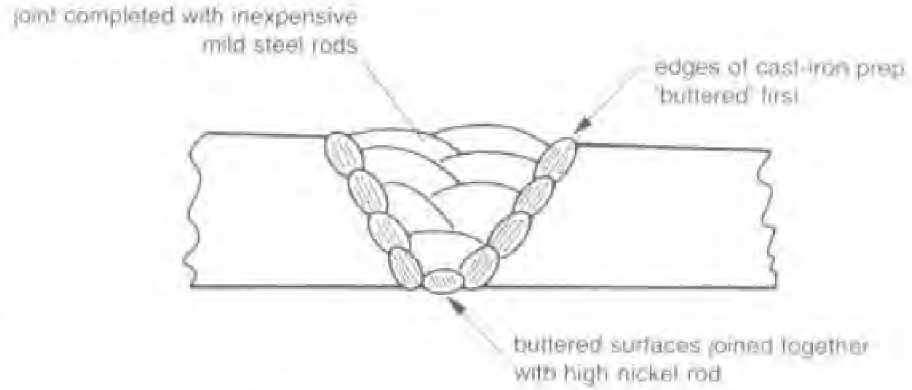
Studding

The strength of thicker joints is improved by studding. Holes are drilled into the joint surface, tapped, and studs inserted. These are welded in, followed by the remainder of the joint. The strength is now enhanced by the studs penetrating well below the fusion zone.

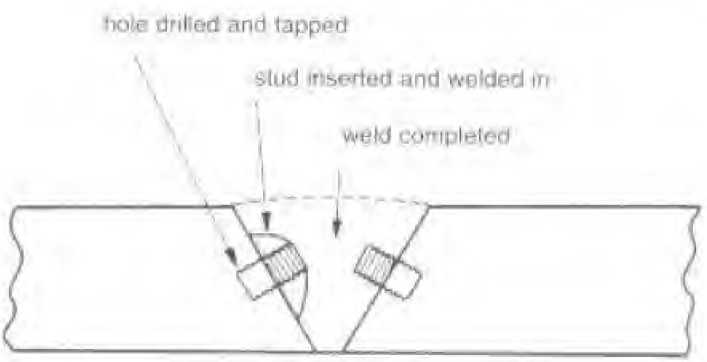
DISSIMILAR METALS

Welding is not possible between the 'light' alloys and the 'heavy' ones; so, for example, a mechanical method or an adhesive is the best way to join stainless steel to aluminium.

Otherwise, if one or both metals is a stainless steel then the filler should match the stronger, higher alloyed material. Dissimilar carbon steels can be welded with a low hydrogen electrode, whilst non-fusion methods are best for combinations of brass, copper, and steels.



Buttering cast-iron

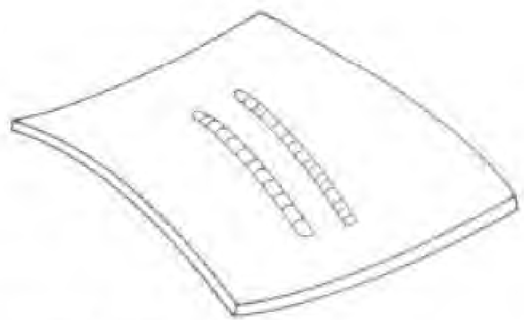


Studding cast-iron

8 DISTORTION CONTROL

A welded joint or fabrication is said to have distorted when it does not finish in the desired shape, angle or size. A job can be prepared and set up with the greatest accuracy, and held together with the highest quality welds but if it is misshapen it will not fit or function properly!

There are two forms of distortion: either the material buckles or its angular alignment is incorrect.



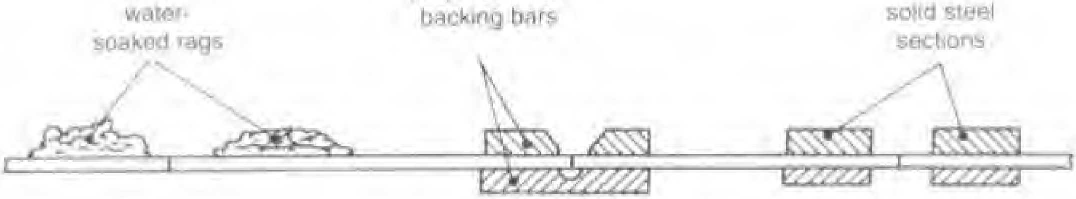
Warping of sheet

BUCKLING

Buckling occurs most with thin sheet but any thickness can warp, particularly in stainless steel. The 'natural' state of metal is to be a little warped so the final stage of production is to make it flat by sending it through a series of rolls. 'Roller flattening' is thus achieved by introducing uneven internal stress. Warping or buckling happens during welding because the heat 'relaxes' the residual stresses in the material which are keeping it flat.

This type of distortion is avoided by keeping the metal as cool as possible. Chills, in the form of water-soaked rags, copper or steel blocks or proprietary heat sinks, can be used to soak up heat as it conducts away from the weld.

Another method is to weld the metal as fast as possible. More intense heat sources put



Use of chills

less volume of heat into the metal so MIG welds heat the metal less than gas ones and large MMA electrodes less than small ones.

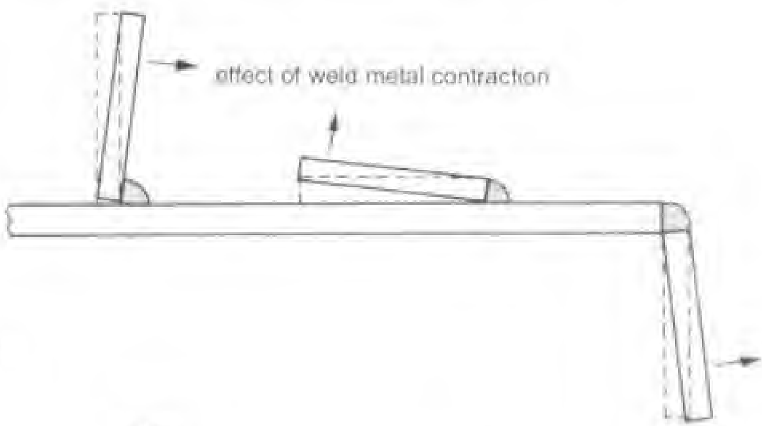
Alternatively a very low heat source can be used, and/or welding can be stopped periodically for the metal to cool as necessary before recommencing.

ANGULAR DISTORTION

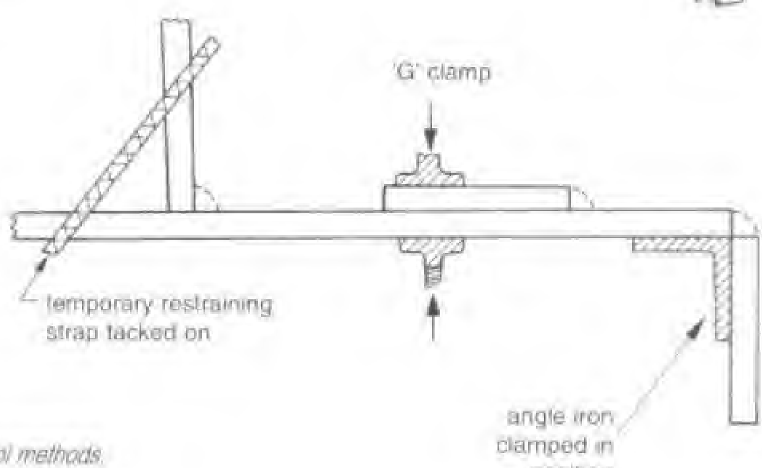
Expansion and contraction provide the welder with his biggest headache. If molten metal is placed in a 90-degree fillet corner at 1500°C and it cools to 20°C then it will contract considerably and pull the metal with it. This is combated by either (a) restraining the joint so that it cannot move or (b) utilizing the movement to produce the desired result.

Restraint

This can be achieved with a wide variety of clamps and vices but it must be noted that they will be more difficult to remove than to put in place because the contracting weld is then exerting a force. Upon removal of the clamp there will still be a small amount of movement.



Angluar distortion in plate.



Angular distortion control methods.

Restraint can be built in by tacking as many items together as possible before starting to weld so that one piece of metal holds others in place. This can be achieved artificially by tacking on cross braces or diagonals, welding up and then removing the braces afterwards.

Controlled Movement

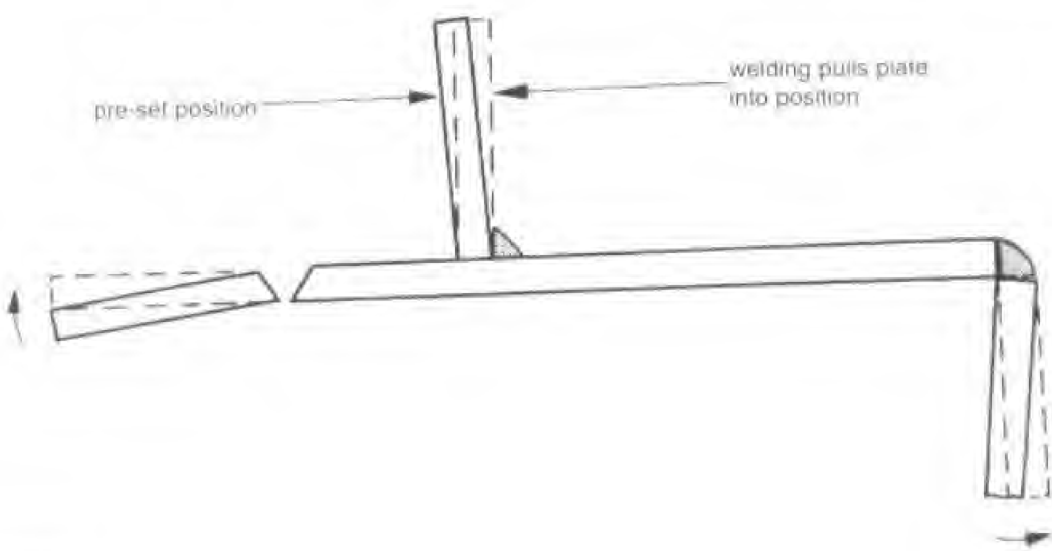
The movement of the joint can be anticipated and used to advantage.

Presetting
If a fillet is expected to pull over about 5 degrees, then setting it back 5 degrees before starting will cause it to be in the correct alignment when welded. Judgement is difficult for one offs but some presetting must improve the accuracy.

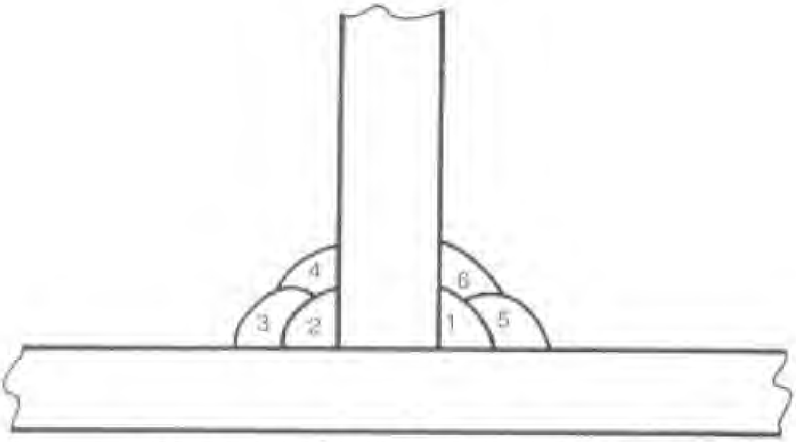
Weld Sequence
This is perhaps the most important and interesting method at the welder's disposal. If welding on one side pulls the plate in that direction then welding on the other side will pull it back again. The 'other' side will sometimes be opposite and at other times adjacent to the previous weld but it must be anticipated to counteract the pull of the first weld, not make it twice as bad! The second weld will not completely pull back the first and the second side may require further welding before returning to the first. In all cases beads are placed so that they pull the joint in the direction required.

DESIGN

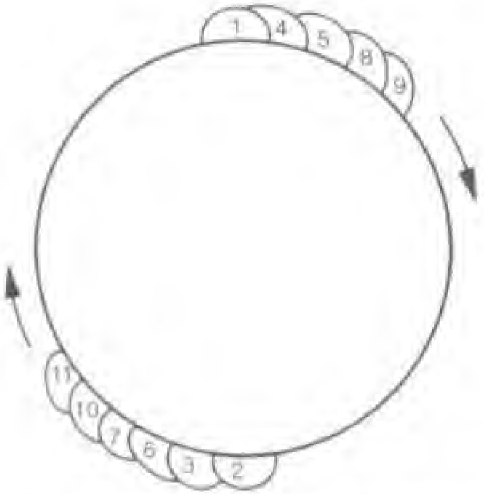
If welding produces distortion (and is expensive) then welding should be kept to a minimum. Joint location and types can reduce the volume of welding, and whenever possible practical welding should be balanced rather than one sided; for example, a



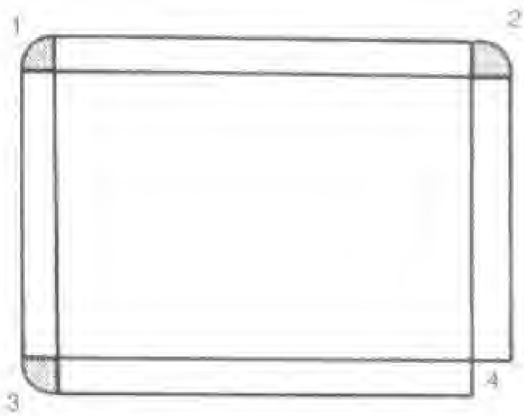
Pre-setting.



welding on opposite sides to counteract contraction

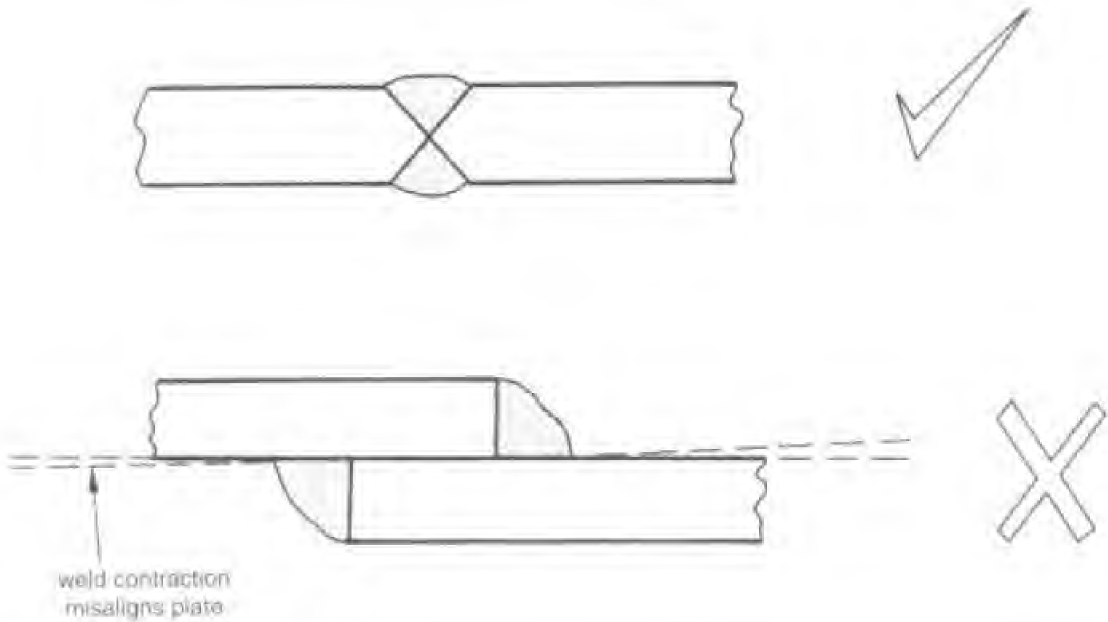


balanced weld sequence to counteract bending



welding on adjacent sides to counteract distortion

Weld sequence – examples



Influence of joint design on distortion

lap joint is structurally weak and also buckles the lower plate surface, whereas a butt joint welded from both sides is stronger, uses less weld metal, can be kept flat and is aesthetically more attractive.

9 QUALITY IN WELDING

The overall performance of a welded joint will depend on four factors:

1. The type of material being welded
2. The consumables used to hold it together
3. The procedure used to make the joint
4. The skill of the welder making the joint

In order to have confidence and reliability in welded work standards are applied in all four areas, typically national ones like DIN in Germany, and BS in Britain, but moving rapidly towards ENs in Europe. Euro Norms are becoming universal across the EC and in Britain are prefixed by BS; for example, BS EN 10 025 is the standard applied for structural steels.

Materials and consumables are subject to quality control during manufacture to ensure compliance with various standards. Welding procedures and the welder's skill are assessed by making and testing specimen welds, which vary in difficulty to reflect particular areas of work. The welder is the most vulnerable part of the system, as his performance may be influenced by many factors. However, working to an established weld procedure should ensure that the joint is not distorted and that the weld is of the correct chemical composition and metallurgically acceptable in terms of grain size and type.

The weld must also be physically sound, fully fused with the parent metal it is in contact with, have no discontinuities or inclusions and a profile which blends smoothly with the plate.

WELD FAULTS AND THEIR CAUSES

Lack of Penetration

The weld fails to fuse fully into the root of a fillet or through a butt joint. Probable causes:

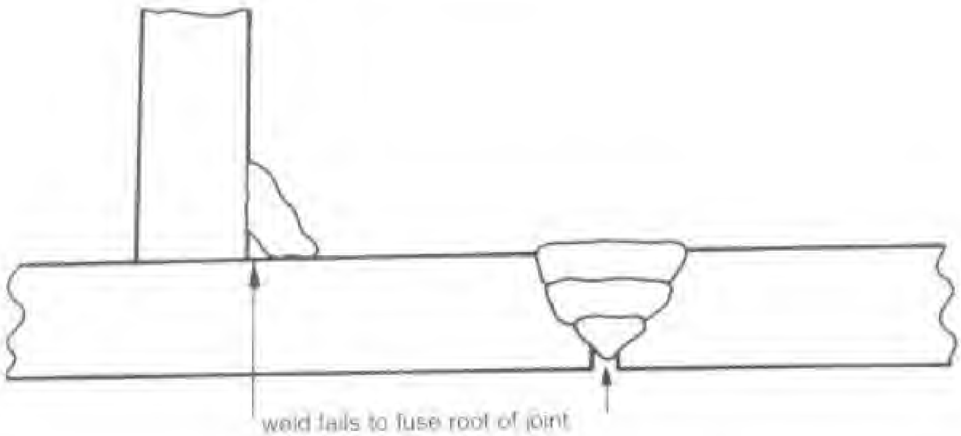
1. More heat is required – use a larger flame or higher current setting.
2. Less filler is needed – use a smaller electrode, lower wire feed speed, or in gas/TIG welding, feed less in.
3. The joint gap is too small or the angle is too acute.

Over-Penetration

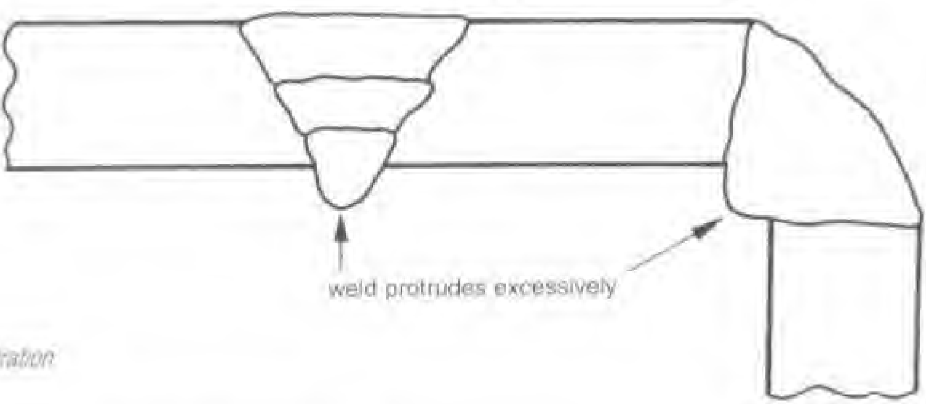
The weld metal protrudes excessively through a butt or breaks through the other side of fillets. The causes are the opposite of those listed above for lack of penetration.

Lack of Fusion

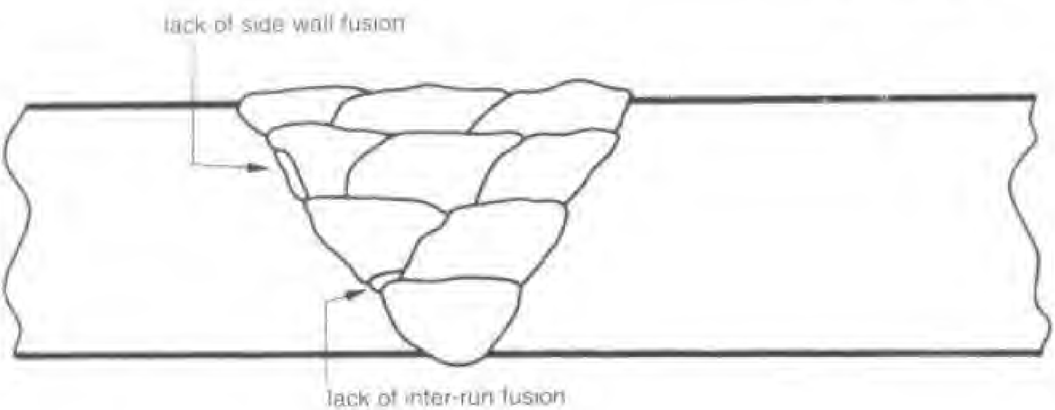
The weld metal fails to fuse at the interface



Lack of penetration.



Over penetration



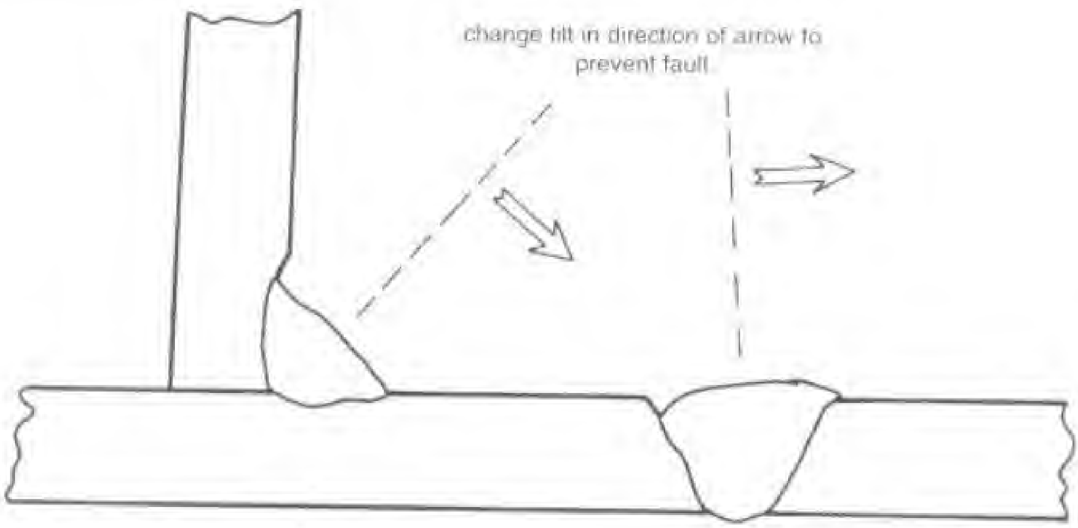
Lack of fusion

This has the same causes as lack of penetration and can be avoided by using more heat/less filler.

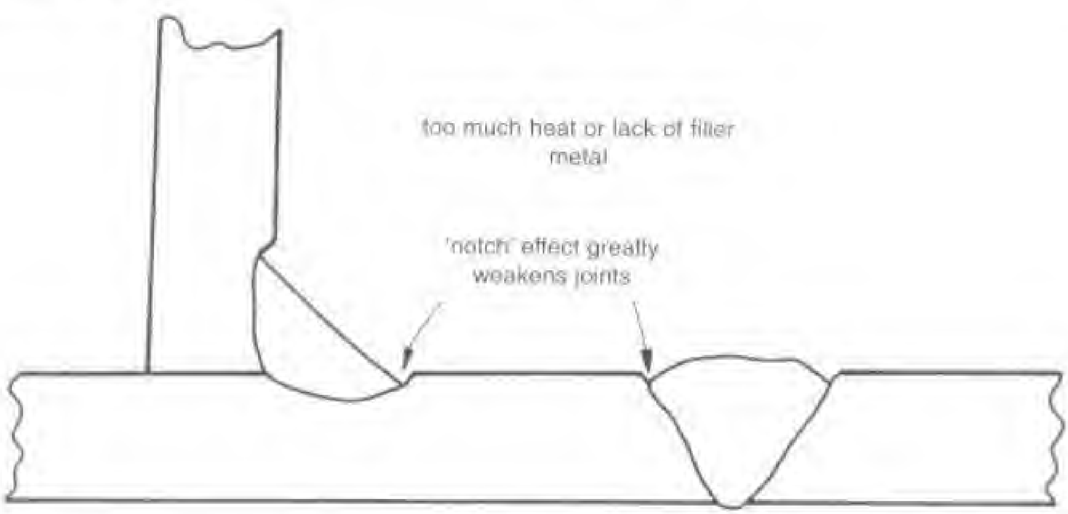
Undercut

The metal has melted away but has not been filled in, leaving a 'notch' at the side of the weld. Undercut on one side only indicates that the angle of tilt (of the torch/gun) did not bisect the joint angle.

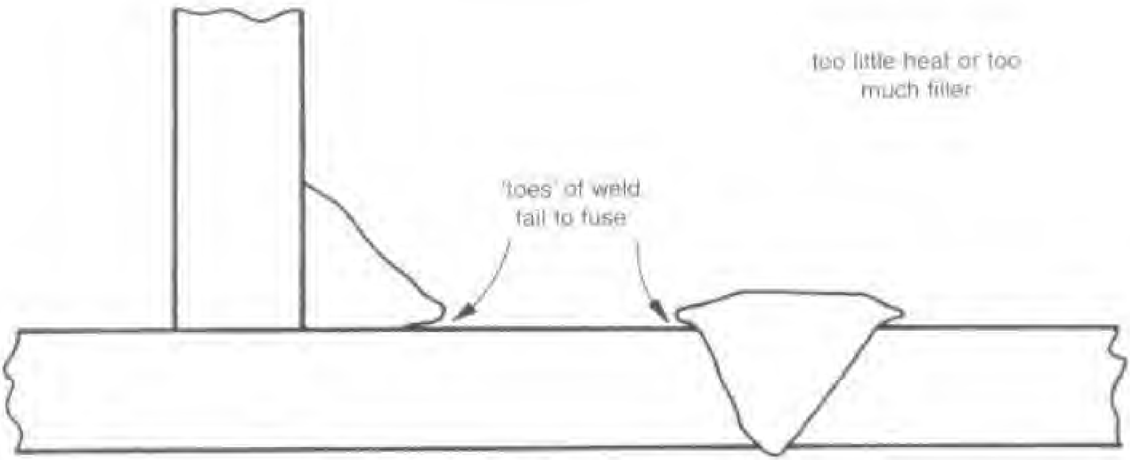
If it appears on both sides then the ratio of heat to filler must be reduced, that is, less heat or more filler is needed.



Undercut – on one side



Undercut – on both sides.



Overlap.

Overlap

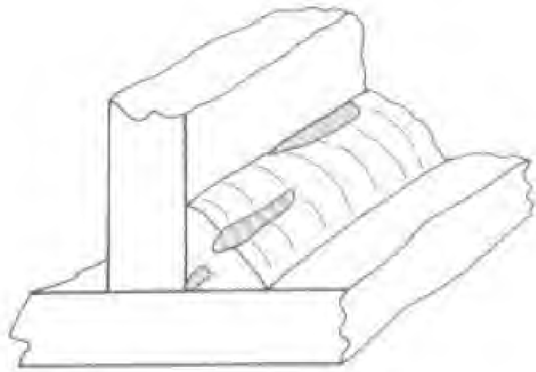
Not common, this is where weld metal spills over the plate surface without having fused to it. When this occurs on one side only, a change in tilt angle is needed, but if it happens on both sides then more heat or less filler is required.

Cold Lap

This is a term applied to MIG welding only but actually means lack of fusion/overlap. It is very difficult to eliminate completely, at restarts generally and at those in aluminium in particular. Higher voltage/wire settings are required or less wire/more voltage.

Slag Traps

These occur in MMA welding only and are voids in the weld metal occupied by slag. The causes are numerous and include a low current setting; acute preparation angle; steep electrode slope angle, or welding over slag or heavy scale.



Slag traps.

Porosity

Gas entrapment is rarely evident on the weld surface, but the traps' spherical form appears as light circles on an X-ray. This problem is caused in stick welding by damp electrode coatings (hydrogen) or in MIG/TIG welding by lack of gas shielding, or from contaminants such as oil and oxide scale.

Blowholes

These are gas holes large enough to appear

on the weld surface and may be due to extreme porosity, or in braze welding occur as a result of too little oxygen in the flame.

Underfill

Part of a butt weld is below the plate surface, causing it to fail any welding test. More filler/passes are required.

Spatter

Particles of weld thrown out on the plate surface, caused by high welding currents, long arcs and damp electrodes in MMA welding, and by too little inductance/too much CO_2 in the shielding gas in MIG welding.

Rough Appearance

Erratic arc length, long arcs and shallow slopes give rise to rough welds, as do damp electrodes and surface contamination.